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RAND

*Finding the Right
Mix of Military
and Civil Airlift,
Issues and Implications*

Volume 3. Appendixes

*Jean R. Gebman, Lois J. Batchelder,
Katherine M. Poehlmann*

*Prepared for the
United States Air Force*

Project AIR FORCE

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Project AIR FORCE

DISTRIBUTION STATEMENT A

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FOREWORD

Shortly after our forces returned from the Gulf War, the Secretary of the Air Force and the Air Force Chief of Staff asked RAND to undertake this research. The work was performed and briefed to the Air Force during fiscal year 1992. The following year, a summary briefing was prepared and presented to the Air Force. Draft documentation was then prepared and reviewed within RAND. During 1994, a revised draft report was reviewed by the Air Force and the aircraft industry.

RAND was asked to perform this work in response to the many changes occurring around the world that may influence the attractiveness of different approaches to the Air Force's investment in its strategic airlift capabilities. Changes have continued to occur through the course of the research and its documentation. They may continue as the Air Force and the Department of Defense continue to grapple with major choices about essential airlift capabilities and the alternatives for providing those capabilities.

The research described in this report can help inform those choices. It explores how the DoD might work toward an affordable strategic airlift capability that has both enough capacity to support major regional contingencies and enough flexibility to go anywhere our nation's interests require the prompt global reach of our combat or humanitarian resources.

Because the DoD's choices in this area involve major investments that will have significant and long lasting implications for future capabilities, we have aimed to provide the Air Force with an indepen-

dent research product based upon a broad analysis of matters we judged to be germane to future choices.

As the research and its documentation progressed, there have been many spirited discussions within RAND and the airlift community. These discussions have contributed importantly to the nature and content of the final report. To share the benefits of many of these discussions with the reader, we have included a third volume. It contains 80 topics that are arranged by subject matter in a set of appendixes.

Some of the topics address the research context (Appendix A), others deal with elements of the research (Appendixes B, C, and D) or differences between this and related research efforts (Appendix E). One set of topics (Appendix F) illustrates how this research might be adapted to take into account the continuing changes that are important to future decisions. The final set of topics (Appendix G) identifies important open issues and suggests initiatives for resolving or narrowing these issues. Some key areas to watch are the DoD's continuing assessment of airlift requirements, the DoD's continuing revisions to the CRAF program, the CINCs' perspectives on the need for capacity and flexibility in the airlift fleet, the DoD's Nondevelopmental Airlift Aircraft program, and the retirement of the C-141 fleet.

PREFACE

Stringent budgets and a changing world prompted the Secretary of the Air Force and the Air Force Chief of Staff to seek an independent estimate of the mix of military and civil airlift that would be sufficient for future needs while minimizing demands on future budgets.

Most of the research for this short-term effort was completed during the first six months of FY 1992, with the remainder of the year devoted to analysis of the Air Force's follow-up questions. The research built upon other RAND work begun in 1990 for the Office of the Undersecretary of Defense for Acquisition (Hura, Matsumura, and Robinson, 1993); reviews of lessons learned from the Gulf War that were conducted for the Office of the Secretary of Defense, the Army, and the Air Force (Lund, Berg, and Replogle, 1993, and Chenoweth, 1993); and research requested by the Vice Chief of Staff of the Air Force that addressed the subject of the Base Force (Bowie et al., 1993). In addition to the airlift analysis methods used in the previously initiated work, this research developed advances in RAND's tools for analyzing life cycle cost, benefits of aerial refueling, aircraft utilization rates, throughput, and airfield access.

As research results were produced, they were briefed to the Air Force throughout 1992. At the Air Force's request, a summary briefing was prepared and provided in February 1993. This report presents the details of the research and findings reported in that summary briefing. This report and its companion volumes (Gebman, Batchelder, and Poehlmann, 1994a, b) are the final documentation for this research. Since completion of the research in 1992, a number of events related to this research have occurred.

- To expand its authority to activate the Civil Reserve Air Fleet (CRAF) without requiring action by the President (which is needed for Stage III), the Defense Department has increased the size of Stages I and II. For example, Stage I for passenger aircraft is 63 percent larger. Stage II for cargo aircraft is 100 percent larger.
- DoD's continuing revisions to the CRAF program are more broadly linking government business to participation in the CRAF.
- Estimated costs for completing the C-17 program have risen, the schedule has been stretched, and for long distances, the airplane's payload has been reduced.¹
- A congressionally mandated Cost and Operational Effectiveness Assessment for the C-17 was completed by the Institute for Defense Analyses in 1993.
- DoD's continuing assessment of airlift requirements is showing increased needs for airlift during the early weeks of a major regional contingency and even greater needs during the early weeks of a second nearly simultaneous major regional contingency.
- The perspectives of the commanders in chief (CINCs) of the unified commands on the need for capacity and flexibility in the airlift fleet are reflected in the outcome of their August 1993 meeting, in which they expressed a very strong desire for a new military-style transport with flexibility like that possessed by the C-17.
- The DoD has launched a Nondevelopmental Airlift Aircraft program to explore alternatives including military- and civil-style

¹The Institute for Defense Analyses has performed a Cost and Operational Effectiveness Assessment. The General Accounting Office has reviewed the status of the C-17 development program. The Defense Acquisition Board has considered restructuring the acquisition program. The Defense Department and the C-17's prime contractor have agreed to a restructuring of the acquisition program, including reduced performance requirements for the aircraft. The Defense Department is considering supplementing its procurement of the C-17 with the purchase of an already developed transport.

transports that might be procured along with or instead of the C-17.

- DoD has initiated an study of strategic airlift force mixes.
- The entire C-141 fleet is now scheduled for retirement by 2005.

Although the appendixes address how some of the changes since the completion of the research in 1992 may affect the appropriate use of our work, we have not tried to update the results of the research to account for the continuing stream of changes.

This report is being published at this time to illuminate issues and to illustrate their implications so as to help inform the choices the DoD faces as it searches for the right mix of military and civil airlift.

This project was conducted within the Resource Management and Systems Acquisition Program of RAND's Project AIR FORCE, the Air Force's federally funded research and development center for studies and analysis.

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SUMMARY

Finding the right mix of military and civil airlift is an extremely complex and demanding task, because it involves difficult trade-offs among operational and cost considerations at a time when there is uncertainty about both the future uses of airlift and the funds that will be available to acquire, operate, and support airlift capabilities. Moreover, there are significant differences in the costs and capabilities of different fleet mixes, and the DoD must justify what it selects as the right mix at a time when there is extraordinary competition for resources.

Given the range of uncertainties in so many key areas and given the complexity of the airlift system, it was not surprising to find that our research had stimulated many useful discussions across a wide range of topics that are important to finding the right mix of military and civil airlift for future needs. The purpose of this volume is to share the essence of such discussions in a way that complements the summary provided in Volume 1 and the technical details of the analysis provided in Volume 2.

For many topics, the material in this volume is in the form of a discussion, with most of the technical details and numbers left to Volume 2. For example, this is the form for the discussion of topics dealing with the research context (Appendix A). In other instances, a topic is addressed by providing additional details on how certain estimates were made. This is done for many topics dealing with the throughput research (Appendix B), the cost research (Appendix C), and the theater access research (Appendix D).

In retrospect, it is not surprising that our research has raised a lot of interest in how and why results of recent airlift analyses differ by such large amounts. In addressing such topics, Appendix E uses some sensitivity results to illustrate the implications of different estimates for key parameter values.

Appendix F discusses how the results of this research might be adapted to the changing conditions that will affect the future airlift fleet. Finally, Appendix G shares some ideas about how the DoD might resolve or narrow uncertainties about key parameters and other matters that are important to the future airlift fleet. Below is a list of the topics addressed in each appendix.

A. CONTEXT FOR THE RESEARCH

1. Separation of Strategic and Tactical Airlift for Analysis
2. Dependence on CRAF
3. Effect of DoD Operation of 747-400Fs on the Likelihood of Activating the CRAF
4. Ability of the DoD to Use Passenger-Style Transports to Carry Passengers
5. Role of Economics in Finding the Right Mix
6. Needs for Capacity and Flexibility
7. Approach to Addressing the Breadth of the Flexible Capabilities That DoD Needs for Air Mobility
8. The Concept of a Core Airlifter to Represent Needs for Flexibility in Airlift Capabilities
9. Gulf War Insights About Capacity Versus Diversity
10. Research Approach and Methods
11. Representation of the Airlift System
12. Mix of Airlift Loads
13. Parallel Delivery Streams
14. Satisfying Demands for Airlift During Peak Periods

15. Modifications to the 747-400F
16. Aircraft Scheduling
17. Management of Crew Changes
18. Efficiency of Matching Loads to Aircraft

B. THROUGHPUT RESEARCH

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21. Influence of Multiple Delivery Streams and Aerial Refueling on Infrastructure
22. Method of Resource Impact Assessment
23. Air Force Pamphlet 76-2
24. Average Payload Performance for the C-5
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27. Average Payload Performance for the 747-400F
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30. Gulf War Ground Times for Loads and/or Servicing
31. Ground Time Planning Factors for Loads and/or Servicing
32. Ground Time for Unscheduled Maintenance
33. Block Speed
34. Analysis Tools Used for Throughput Calculations
35. Analysis of Brigade Airdrop

C. THEATER ACCESS RESEARCH

36. Evolving Knowledge of Issues in Assessing Runway Suitability
37. AMC's Concepts for Sustaining Airfield Operations
38. AMC's Approach to Analyzing Runway Suitability
39. Military-Style Transport Features That Increase Access to the Theater
40. Range of Needs for Intratheater Airlift
41. Significance of Comparative Access Capabilities of the C-130 and the C-17
42. Role of C-17 in Theater
43. Basis for Additional C-130 Procurement
44. The C-17's Ability to Use Runways Not Usable by Civil-Style Transports
45. The C-17's Comparative Ability to Support Major APOD Operations
46. The C-17's Comparative Ability to Support Limited Operations During Wartime

D. COST RESEARCH

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50. Determination of Fleet Sizes
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53. Cost Data Sources
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G. IMPORTANT OPEN ISSUES

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- 79. Aerial Refueling Issues
- 80. Fleet Operational Issues

CONTEXT FOR THE RESEARCH

Because the context for the research provides the basis for the analysis and its chief results, this appendix examines seven significant dimensions of this context: the research question, needs for strategic airlift, the research approach and methods, representation of the airlift system, mix of airlift loads, airlift delivery timelines, and aircraft modifications and operations.

THE RESEARCH QUESTION

The research question posed by the Air Force (Volume 2, Chapter One) had significant implications in three areas that shaped the research context and the basis for the analysis and its chief results: separation of strategic and tactical airlift for analysis, the role of national airlift policy, and the role of economics in considering alternative approaches to satisfying airlift needs.

Separation of Strategic and Tactical Airlift for Analysis (Topic 1)¹

Traditionally, airlift has been separated into intertheater (strategic) airlift and intratheater (tactical) airlift when evaluating alternative mixes of military and civil airlift. In keeping with this tradition, the

¹During the course of the research, and the preparation of its documentation, there have been many useful discussions about the issues and the research. This volume shares the substance of most of the topics that have been discussed. The topics are numbered to facilitate cross-referencing among related topics.

Air Force requested a research effort focused on intertheater airlift. We discussed this aspect of the scope of the research with the Air Staff (AF/XOFM). The many factors that seemed to make this the wisest course included (1) the already broad scope of the research effort, (2) the significant complications that would be introduced by attempting a heretofore unprecedented joint analysis, (3) the DoD's lack of a clearly articulated approach to establishing intratheater airlift needs,² (4) the ample supply of intratheater airlift resources (less than one-third was used in the Gulf War), (5) the common use of surface transportation within theaters, and (6) the DoD's continuing practice of treating inter- and intratheater airlift separately in the resource-allocation process.³

Role of National Airlift Policy

The role of national airlift policy manifested itself in shaping the research context in three subject areas: dependence on CRAF, effect of DoD operation of 747-400Fs on the likelihood of activating the CRAF, and the ability of DoD to use passenger-style transports to carry passengers.

Dependence on CRAF (Topic 2). National airlift policy seems to have leaned toward minimizing the size of the airlift fleet operated by the military by maximizing the nation's dependence upon the CRAF. However, the Gulf War demonstrated that the large-air-carrier segment of the CRAF had far less reason to support an activation of the CRAF than the small-air-carrier segment. Thus, focusing solely on maximizing DoD's dependence upon the CRAF, although economically attractive, may be unwise.

The goal should be a dependable airlift capability that is militarily sufficient in its level and mix of capabilities, dependable in its availability, and economically efficient. If such a goal conflicts with cur-

²In contrast, for intertheater airlift, the DoD uses the defense planning guidance to develop scenarios that it uses to size forces and evaluate their transportation needs for sealift and airlift.

³There is a further consideration that the ground march for large units is faster than airlift unless the DoD has a large number of C-17s and forward bases.

rent interpretations of national airlift policy, either the interpretations or the policy need to be reviewed in the light of such a goal.

Effect of DoD Operation of 747-400Fs on the Likelihood of Activating the CRAF (Topic 3). It is not obvious that DoD operation of a fleet of 747-400F transports would reduce the likelihood of activating the CRAF during a major airlift emergency.

Our analysis of the CRAF (Volume 2, Chapter Three) found that its preservation is economically important to the DoD and would be enhanced by making sure that the military airlift fleet is large enough and versatile enough that the CRAF would rarely have to be activated. This finding is driven by the observation that activation, although financially attractive to small air carriers, introduces financial risks that the large carriers would prefer to avoid.

Thus, frequent use of civil air carriers' assets should be confined to those air carriers interested in providing such services. For the occasions when considerably more airlift is needed, the DoD should aim to have a large enough military airlift fleet so that the uninterested air carriers are rarely called upon. Our premise is that, if those carriers are only occasionally inconvenienced, they are more likely to remain committed to the CRAF program.

Addition of the 747-400F to the military airlift inventory would broaden the military's capabilities to include efficient movement of bulk cargo and, for deployments with significant needs to deliver bulk cargo,⁴ our research finds that it would provide greater airlift capacity for a fixed level of DoD investment in the air mobility mission area. With a significant capacity to move bulk cargo, without tying up its military-style transports, the DoD would be less dependent upon the activation of the CRAF.

Ability of the DoD to Use Passenger-Style Transports to Carry Passengers (Topic 4). If DoD operated a fleet of large transports originally designed to carry passengers, it is unclear whether or not it would be allowed to plan on using those aircraft for carrying passen-

⁴For deployments where the amount of bulk cargo exceeds 38 percent, our analysis shows that the Option E fleet with 747-400Fs has greater capability than the Option A fleet with C-17s (see Chapter Four of Volume 2).

gers during an emergency if passenger movement were more critically needed than cargo movement.

Air carriers presumably would be uncomfortable with DoD operation of a large fleet of passenger-style transports, even those converted to freighter configuration, because such aircraft could be used to carry passengers as the Military Air Transport Service did during the 1950s.⁵

Some level of discomfort may, however, help sustain interest in the CRAF. In any event, whether the air carriers could lobby the government to preclude the acquisition of the 747-400F is speculative and lacking somewhat in support in view of the government's existing operation of a fleet of C-9 transports, which are military derivatives of the DC-9.

Role of Economics in Finding the Right Mix (Topic 5)

A proper research context must provide an opportunity to examine both economic and operational considerations.⁶ DoD policy that the Services bear the responsibility for organizing and equipping to meet the combat needs of the CINCs means that the CINCs do not have the final word regarding the organizing and equipping of the airlift fleet. Although important, the perspectives of the CINCs cannot be the final determinant, because they do not have the responsibility for allocating resources to meet the full range of DoD responsibilities.

Furthermore, even though airlift is such a complex function of the DoD, both DoD precedent and the current fiscal realities mean that airlift cannot be exempt from cost-benefit analyses of alternative approaches to meeting DoD's air mobility needs.

On the other hand, the research context must adequately address both economic and operational considerations. To provide some

⁵Because this issue has been raised on several occasions by industry and airlift analysts, it may warrant further examination in the event that the DoD considers the acquisition and operation of a large civil-style transport.

⁶Some have suggested, however, that the choice of the right mix should be driven by an analysis of airlift requirements. The implication is that the requirement must be funded even if it means either achieving economies elsewhere within the defense budget or increasing the defense budget.

operational balance to the research context, we assumed the deployment of armored and mechanized units in the analysis scenario, an assumption that goes beyond what is usually assumed in air mobility analyses.

Other operational possibilities, however, were not addressed. Most notably, we assumed that neither prepositioning nor sealift was a factor in our analysis scenario. These exclusions, though, were purposeful in that they result in a greater need to deliver outsize materiel by air, which was consistent with our aim to consider a tough scenario in terms of the inclusion of outsize materiel.

NEEDS FOR STRATEGIC AIRLIFT

The nation needs both sufficient capacity for quick response and sufficient flexibility in airlift capabilities to support going anywhere when needed. To quickly deliver a large force, the strategic airlift system needs a large fleet of transports (fleet capacity) and needs bases with sufficient runways, ramp space, fuel, and ground support (infrastructure capacity) to receive and prepare transports quickly for their next flights. The airlift system also needs flexibility to make deliveries to places with limited infrastructure. Delivery flexibility includes such capabilities as airdrop and operations into austere airfields.

Needs for Capacity and Flexibility (Topic 6)

An appropriate research context should provide the opportunity for consideration of two critical needs: capacity and flexibility. Given fiscal constraints, these needs can only be met with a mix of transports, some of which satisfy needs for capacity (as has the CRAF), and some of which offer flexibility by having a variety of capabilities for delivering loads. The search for the right balance has been the core interest of our research.

The options explored by the research cover a spectrum of possibilities (see Volume 2, Chapter Four). The option that seems most attractive, in view of its cost-saving potential, would come at the price of reduced capacity of the type that is the hallmark of the diverse capabilities of the military-style transport. On balance,

however, the trade may not be beyond the range of what reasonably should be considered, given the severity of the fiscal constraints facing the DoD.

The DoD would still have a significant capacity to deliver early loads that have a concentration of combat equipment and other equipment required to establish theater operations (see Volume 2, Chapter Four). Moreover, it would have a higher level of overall capacity to move and sustain the follow-on forces that are also needed. With the closure of overseas bases, both the initial needs and the follow-on needs for airlift have increased.

Furthermore, the trade does not seem beyond the range of what reasonably should be considered, because our analysis (Volume 2, Chapter Four) has included an accounting of the wide range of transportation needs. It has included the militarily unique need for roll-on, roll-off capability for moving vehicles. It has included the need to load and unload pallets on civil-style transports quickly. We have separately examined the need for brigade airdrop. And we have extensively explored the matter of access to austere airfields (Appendix C).

Approach to Addressing the Breadth of the Flexible Capabilities That DoD Needs for Air Mobility (Topic 7)

Although an appropriate research context must provide the opportunity to consider the full range of air mobility needs, analyses traditionally have focused upon the greatest need, while assuring the ability to handle the other lesser needs.

Although our research focused on strategic airlift capabilities for major regional contingencies, we also examined the brigade airdrop and other mission needs. Each of the options in the final set of five (Options A through E in Volumes 1 and 2) appears to have adequate capabilities to address the other needs examined by our research.⁷

⁷See Tables 4.8 and 4.11 in Volume 2.

The Concept of a Core Airlifter to Represent Needs for Flexibility in Airlift Capabilities (Topic 8)

To help ensure that considerations of alternative transports provide appropriate attention to the needs for flexibility in airlift capabilities, the DoD has recently been using the concept of a core airlifter. Because there are some characteristics of the military-style transport that the DoD must preserve in a significant number of aircraft, it has established a requirement for procuring a new core airlifter with those characteristics. Taking such a validated requirement as the starting point was not possible in 1992 because the CINCs had not established it until near the end of FY 1993.

Instead of starting with a presumption about the type of aircraft that should be procured next, and remembering that there are already a significant number of military-style transports in the inventory, we focused on the air mobility missions and tasks to be performed and on the costs and capabilities of alternative fleets of aircraft to perform those missions and tasks. Of course, a different approach might compare the characteristics of different transports. With the latter approach, the military-style transport is the clear winner over the civil-style transport in terms of the diversity of militarily meaningful capabilities. On the other hand, for some missions and under certain circumstances, the civil-style transport is economically superior. We judged that simply comparing the core airlifter with the economic airlifter would not add much to informing the tough choices that lie ahead. Thus, we chose an approach that compares the costs and capabilities of alternative mixes of aircraft. With this approach, however, we have tried to remain mindful of the flexibility that the military-style transport offers. To help do that, we evaluated alternative fleets in terms of their comparative abilities to deliver different classes of cargo and to access different types of airfields. We believe that our analyses of such considerations have provided a way to understand the relative abilities of different fleets to perform those kinds of militarily unique missions that have been associated with the concept of a core airlifter.

Gulf War Insights About Capacity Versus Diversity (Topic 9)

Even though the Gulf War experience with bulk cargo is an important data point, an appropriate research context must include that data point without overemphasizing airlift capacity at the expense of diversity in airlift capabilities.

Although airlift studies of the past three decades have focused largely on deploying the rolling stock constituting the Army's unit equipment—most often to reinforce NATO—the dominant category of materiel moved by air for the Gulf War was what could be packaged on pallets measuring 7.3 × 9 ft (W × L) with a maximum height of 8 ft. The DoD has labeled materiel on such pallets as bulk cargo, which includes expensive test equipment, spare parts, food, clothing, and ammunition. In all phases of the Gulf War airlift, such palletized (bulk) cargo was the single largest category of cargo to be airlifted.

Because the bulk cargo category includes such a diverse range of materiel in quantities that are difficult to forecast and model, airlift studies have tended to focus on equipment that is easier to measure and count, such as tanks, trucks, and helicopters.⁸ Moreover, because many types of bulk cargo can be prepositioned, there has been a tendency not to consider fully this class of cargo for shipment by air.

Thus, the Gulf War airlift—the closest test yet of the strategic airlift scenario for which the air mobility capabilities have been sized and designed—is an important data point regarding the nature and amount of cargo that falls in the bulk category. Of course, only limited data are available, and other conflicts in other regions may have different proportions of cargo types. Even so, there are significant lessons to be drawn from the Gulf War experience.

The recognition of bulk cargo as a significant part of the total airlift task partly acknowledges a need that has always been present but is, also perhaps, a consequence of deploying to a theater lacking a significant infrastructure, unlike that in Europe.

⁸For example, for over two decades, analysts have used fairly thorough equipment lists to analyze how transports might be loaded to maximize throughput when delivering equipment for different types of units. Comparable lists of the bulk cargo needs of such units have not been constructed and analyzed as thoroughly.

Although the assumptions that we have used for bulk cargo were influenced by the Gulf War experience, we have taken the low range of the estimates for that experience (from the first 30 days) for the closure time calculations for each option.⁹

We recognize that there is uncertainty about how high the demands for bulk cargo may actually be, especially during the early weeks before significant needs for sustainment materiel are generated by the forces arriving in theater. To deal with any lower-than-assumed levels of bulk cargo, especially during the early weeks, this report suggests that the Air Force select a civil-style transport already capable of carrying significant amounts of oversize cargo (see Volume 2, Chapter Four). This led us to focus on the 747. The report also suggests exploring provisions for carrying troops.

Although we believe the Gulf War experience provides a reasonable basis for our treatment of bulk cargo, we certainly recognize the limitations of that single data point. To hedge, we encourage broadening of the prospective applications of the 747. With such broadening, we find that the options we examined are robust across plausible variations in the assumed proportions for bulk cargo.¹⁰

RESEARCH APPROACH AND METHODS (TOPIC 10)

The soundness of the research approach and methods that provide the skeleton for the analysis of alternative fleets is determined by the depth and breadth of the analysis, the examination of ways to relax airlift system constraints, the exploration of ways to better realize the potential of each type of transport, the effect of simplifying assumptions and the scenario on the relevance of results, the range of cargo mixes and combinations of airlift fleets considered, the robustness of the analysis, and the adequacy of measures used to evaluate alternative fleets.

⁹See Figure 2.5 in Volume 2, Chapter Two.

¹⁰For example, if bulk cargo accounts for only 38 percent of the load mix, then Option E (see Chapter Four of Volume 2) has the same total capacity in total tonnage (but not oversize) as Option A. If 60 percent of the cargo is bulk, Option E has 45 percent more capacity than Option A. On the other hand, if no bulk cargo is delivered by air, then Option E has 85 percent of Option A's capacity.

As discussed in Volume 2, Chapters One and Four (and in Appendixes B, C, and D of this volume), because of the depth and breadth of the work, as well as the innovative approach and methods employed, we believe that this research at least matches and in important respects exceeds the standard for quality and relevance set by other air mobility research efforts. Although other research may have delved more deeply or more broadly into certain facets, we believe that, overall, the research approach and methods used in this work represent a significant advancement.

Depth of Analysis

In several areas, the analysis went deeper than most past or subsequent studies. Examples include analyses of transport utilization rates (a major research thrust that had significant effects on the design of the analysis), airlift deployment cycle times for specific divisions, and the effectiveness of aerial refueling in increasing airlift productivity. In other areas, the approach to the research followed new paths that look different from the traditional ways in which certain matters are addressed. In these areas, it is not an issue of inadequate depth but rather issues about the appropriate course for the research. Two examples (addressed in Volume 2, Chapter Four) are the approach to the airlift infrastructure and the approach to loading aircraft.

Breadth of Analysis

In several areas, the research is broader than most past or subsequent studies. These include the effect of unscheduled maintenance on aircraft utilization rates, the economics of CRAF, airfield access, and runway durability. We know of no other research effort that included all of these factors.

Relaxation of Airlift System Constraints

A major part of the research focused on using lessons from the Gulf War airlift to explore ways to relax airlift system constraints to increase airlift productivity.

Realization of Each Transport's Potential

Significant attention was placed on understanding the strengths and weaknesses of each type of transport and on understanding how each transport might best be used to fulfill its potential to contribute to airlift needs. In some cases, this would require changes to traditional approaches to doing business. Where it seemed reasonable, such changes were reflected in the assumptions and scenario that we used.

Effect of Simplifying Assumptions on Relevance of Results

Most of the assumed values for the many parameters used in our analysis were taken from official sources. Exceptions (addressed in Appendix B) include situations in which other evidence suggests an alternative that may be more appropriate. Aircraft utilization rates are an example. Other exceptions (addressed in Volume 2, Chapter Four) include situations in which airlift productivity can be improved by changing the traditional approach to doing business. Of course, for those parameters for which we have not used official planning factor values, that raises an issue about the relevance of our results. To help the reader judge the relevance and appropriateness of our approach to such parameters, we have tried to document the rationale for our approach, as well as the method and the major assumptions.

Effect of the Scenario on Relevance of Results

The scenario (see Volume 2, Chapter Four) departs from the traditional approach used in many studies to provide a deeper analysis of certain critical issues (e.g., utilization rates and aircraft loading) and to reflect changes in business practices to increase airlift productivity. The scenario is fairly broad in that it examines the deployment of five different types of divisions¹¹ that have different mixes of loads. In effect, five different deployment cases are examined. The scenario and its relevance are further examined later in this appendix and in Appendix B.

¹¹See Tables 4.1 and 4.11 in Volume 2.

Range of Cargo Mixes Considered

The range of loads ran the spectrum from infantry units with many people and relatively small amounts of equipment to armored units with a lot of large and very heavy equipment.¹² Although cargo mixes for Air Force, Marine Corps, and Navy units were not considered directly, it is reasonable to assume that the mixes of loads that their units would generate are no more stressful in terms of the size and weight of equipment than the Army units used in the analysis.

Combinations of Airlift Fleets Considered

Many prospective combinations of fleets were considered by the screening and sensitivity analyses. From that work, we found a few dominant considerations that helped reduce the number of combinations warranting in-depth analysis. First, for moving outsize materiel, only the C-5 and the C-17 are candidates. Second, for long-range delivery of large loads of bulk cargo, the 747-400F is the most efficient transport. Third, of the civil-style transports, the 747-400F has the greatest capability to carry oversize materiel. Fourth, the military-style transports benefit most from aerial refueling. We used these four considerations to design the five options that were then analyzed in greater detail.

Robustness of the Analysis

Many sensitivity analyses were conducted to test the robustness of our approaches to key parts of the analysis and to test the robustness of the fleet-mix options. Aircraft utilization rates, alternative concepts of operations for aerial refueling, operations and support costs, and aircraft payloads were areas that received special attention. Significant results from these sensitivity analyses are contained in Volume 2, Chapter Four. Other results have yet to be documented.

¹²See Table 4.1 in Volume 2.

Adequacy of Evaluation Measures

Both performance of the airlift system and costs were examined from multiple perspectives. For example, measures of airlift system performance included evaluation of the flexibility of delivery capabilities in terms of airfield and load characteristics.

REPRESENTATION OF THE AIRLIFT SYSTEM (TOPIC 11)

The adequacy of the representation of the airlift system that provides the setting for evaluating alternative fleets depends upon the modeling approach, the assumed network's routes and bases, and the ability of the DoD to make investment choices that have been informed by the results based upon such a representation. We believe that our approach to these matters at least matches that of other air mobility research efforts. Although other research may have dealt differently with the details of networks, routes, and roles of individual bases, we believe that, overall, the representation of the airlift network used in this work represents an advancement and a reasonable approximation for evaluating fleet investment alternatives.

Modeling Approach

For several years, the Air Mobility Command (AMC) has been sponsoring research at national laboratories and elsewhere that has been aimed at developing a dynamic representation of the airlift system that could be used to support air mobility research. Current efforts are focused on the Mobility Analyses Support System (MASS), an early version of which was used by AMC to support analyses of how aerial refueling might be used to increase airlift productivity. MASS is an evolving suite of mobility models that include the Airlift Flow Model (AFM) and the Airlift Cycle Analysis Spreadsheet (ACAS) model. MASS-AFM, with features still in the development-and-verification stage, was also used to support the C-17 Cost and Early Operational Assessment (COEA) performed by the Institute for Defense Analyses (IDA).

Although features of MASS-AFM allow the use of stochastic processes to represent the availability and use of support equipment, such as refueling and loading equipment, other considerations are dealt with

much more simply. For example, unscheduled maintenance on transports is represented in a more sophisticated manner in our model.¹³ Because the airlift system is so complex, choices must be made about where it is most beneficial to invest in the depth of the representation of the airlift system. We had the further advantage of being able to tailor our representation to the needs of this analysis, rather than using a representation that had been developed for another purpose.

While MASS-AFM and other prospective tools have been undergoing development by outside experts, the planning staff at AMC has developed a model that takes a much simpler view of the airlift system. For example, this model assumes steady-state conditions rather than the dynamic conditions captured in MASS-AFM. The model is also implemented as a spreadsheet. Models like this Airlift Cycle Analysis Spreadsheet (ACAS) model have been characterized as simplistic and unsophisticated, partly because of their simplifying assumptions and partly because of their implementation in the form of a spreadsheet. All models, however, are based upon simplifying assumptions, and even complex models can be implemented as spreadsheets.

Those familiar with the ACAS model recognize that the model is a very clever and sophisticated representation of most of the important aspects of the airlift system. Because it is a spreadsheet, people may erroneously think of it as a simplistic table with a few rows and columns for adding numbers. It is actually a model that in former times probably would have been coded in FORTRAN or some other application language. The spreadsheet format is used to organize a complex set of equations that work behind the scenes of the many cells in the spreadsheet. To those familiar with the equations, the model looks more like a traditional computer program than a spreadsheet.

Much of the DoD-sponsored research on air mobility in recent years has used ACAS, a derivative of ACAS, or a model embodying many of ACAS's core concepts. AMC uses it often. Previous RAND research used ACAS and a derivative of ACAS. Other, prior RAND research used the steady-state flow assumptions in ACAS. In addition to hav-

¹³See the discussion of the necessity for utilization rates to reflect aircraft characteristics accurately, in Volume 2, Chapter Four.

ing AMC run the MASS-AFM model, IDA used the ACAS model in its COEA for the C-17; many of IDA's results seem to have come from their use of the ACAS model.

The model used to produce the results in this report built upon the core concepts in ACAS and substantially added to them by modeling the availability and utilization of transport aircraft. RAND's approach explicitly models the underlying processes to calculate utilization and availability (see Volume 2, Chapter Four).

Network

Several networks were used in the course of our research. The final five options were evaluated with a network that explicitly included 19 air bases for operating the military transports (including any 747-400Fs that might be part of the military inventory). These bases included places for loading and unloading transports, places for refueling and performing maintenance while en route, and places for changing aircrews. Although we included 19 bases in our network, we recognize that an actual major regional conflict like the Gulf War will likely involve over 100 APOEs and over 30 APODs. In our analysis, international airports were assumed to provide additional places for en route support of the CRAF transports, as happened during the Gulf War airlift. We know of no other airlift research effort that has used a more complex network for evaluating the comparative performance of alternative airlift fleets.

Other research efforts have, however, taken a different approach regarding the capacity of airfields to handle the flow of aircraft. Whereas AMC and others have used assumed constraints on the number of aircraft that may be on the ground simultaneously at each air base, we have taken a different path of assessing the comparative needs of different fleets for the specific resources that may cause constraints to occur. This issue of maximum on ground (MOG) constraints is explored further at other points in this document. (See Topics 20, 22, and 57.)

Routes

At the time of our research, AMC was unable to satisfy our request for routes for the five Army divisions used in our scenario. The Air Force Fellows on our project team, including a pilot with tanker experience, worked in consultation with the AMC/XPY staff to develop what all agreed at the working level were reasonable routes for the purposes of our research. Civil airports were used for CRAF transports, as was the predominant practice for the Gulf War airlift. Of course, host-nation approval must be sought to use civil airports, and hazardous materiel must go through military airfields.

Although the use of Lajes was not an issue at the time of the research, the Air Staff's current position is that Lajes should be used only to support tankers; transports should be routed through other bases. We found that Lajes, however, is most needed by the C-17 because of its comparatively shorter range capabilities. If Lajes were unavailable in our analysis, the performance difference between Options A (C-17) and E (747-400F) would have been even larger.

Requiring all aircraft to stop at an in-theater recovery base and at a main AMC base in CONUS to change aircrews is another issue that has arisen since the completion of the research. The position of the Air Staff is that it is operationally unrealistic to change air crews at aerial ports of embarkation (APOEs) and aerial ports of debarkation (APODs), as was assumed in RAND's analysis. This issue has the biggest impact, because it reduces the effectiveness of aerial refueling (Option D). It also reduces Option E's performance, but probably by less than a few percent.

Bases

A couple of basing matters seem to affect all air mobility analyses and all fleet mixes. Two such factors have not been addressed in our research: (1) host nations may deny access to particular air bases (military or civilian), and (2) some air bases may prove to be unwise choices for vulnerability reasons at the time of a conflict.

The distribution of APODs selected for RAND's research scenario was intended to provide a representative distribution of locations of APODs across a theater, as was the case for the Gulf War airlift. Other

locations for the APODs in Saudi Arabia would not have affected the relative airlift mission cycle times.

If, on the other hand, only two APODs were available for the theater, there could be problems handling the flow of transports because of limited supporting resources, such as fuel or ramp space. This matter of air base resources is discussed later (see Topics 20 and 22).

Since the completion of this research, the Air Force has become more interested in the use of recovery bases located in theater or near the theater so that transports could accomplish all (or most) of their refueling and crew change activities away from the APOD (refueling) and away from the otherwise normal en route bases (crew changes) nearest to the theater.

Also since completion of the research, it has become more evident that the availability of resources for refueling the military-style transports in theater was problematic during the Gulf War. The civil transports had less difficulty, perhaps because they use commercial rather than military fuel, or perhaps, as suggested by the Air Staff, they were given priority over the military's transports because the civil transports were being operated on contracts. Although our research did not evaluate the recovery base concept,¹⁴ it would seem sensible in the absence of aerial refueling. In the case of aerial refueling, however, changing air crews at the APOD would eliminate a time-consuming ground stop at a recovery base.

Again, since completion of the research, the Air Force has also expressed increased interest in using its East Coast bases to conduct all maintenance for transports involved in a major regional contingency lying east of the United States. Although the Gulf War experience apparently provides some evidence in support of such a concept, we have not evaluated the capacity of the East Coast bases to handle all of the workload. However, this maintenance matter would have only a small effect on the results.

¹⁴Apparently, the recovery base concept was not of primary interest to AMC at the time of our research, because it was not identified as an interesting possibility when we reviewed our scenario and routes with the AMC staff.

Investment Decisionmaking

Because the representation of the airlift system used in any research effort is an approximation to reality for the scenario(s) examined, the DoD also needs to avail itself of the results from other research efforts in which such matters as prepositioning, sealift, and basing may have been examined.

MIX OF AIRLIFT LOADS (TOPIC 12)

To evaluate the comparative ability of alternative airlift fleets to respond to a range of plausible future needs, the mix of loads used in an analysis scenario needs to provide a reasonable research context in terms of the relevance of the scenario's load mix to DoD's expected needs, the rationale for the scenario's deviations from the DoD's expected needs, the toughness of the scenario's load mix, and the approach to characterizing the scenario's load mix.

Scenario's Relevance to DoD's Expected Needs

The approach that the research took to formulating the load mix portion of the analysis scenario¹⁵ departed from the traditional practice of using the current statement of the airlift requirement. Instead, we sought to establish a load mix of more enduring value in terms of understanding the differences among alternative airlift fleets. The need for such an approach has since been demonstrated. As our research was being completed in 1992, the 1992 Mobility Requirement Study identified a requirement to support a single major regional contingency (MRC). That has already been overcome by the new requirement to support two nearly simultaneous MRCs. As the level and composition of the U.S. armed forces continue to evolve to meet changing threats and budgets, further changes can be expected in the perceptions of the airlift requirement.

When the research was started three years ago, the DoD was in the midst of reevaluating its needs for strategic airlift, as it is today and as it may for some time to come, as downsizing and reorganization

¹⁵For the load mix used in the analysis of closure times, see Tables 4.10 and 4.11 in Volume 2.

continue within the DoD. To support serious research of major investment alternatives, we recognized the need to distance the analysis from a never-ending process of reanalyzing the latest changes in the officially validated requirement.

Rationale for the Scenario's Deviations from DoD's Expected Needs

In formulating the research scenario, our goal was to construct a situation that would be a reasonably stressful test of airlift capabilities to ensure that the fleet could handle a broad range of airlift needs. Rather than predict the variety of future needs and actual situations that will materialize, our aim was to construct a test that was sufficiently stressful that a reasonable range of future possibilities could be handled appropriately by the airlift fleet.

The DoD continues to pursue a different course of trying to pin down the real airlift requirement in terms of its plans for strategic mobilization to support major and lesser regional contingencies. Not only is this course fraught with the problem of continuing change, but it may be the wrong investment approach altogether, because it focuses on agreements about expected situations. It does not address the possibility that future needs may deviate from the expected "requirement," and it does not address the nature and the extent of the need to be prepared to handle such excursions. Yet it is precisely such needs and the recognition of their importance that justify many of the capabilities unique to the military-style transport.

Consider, for example, the problems that can arise when we focus on expected situations. The availability of sealift is a key assumption of continuing efforts to pin down the real airlift requirement. Is it plausible that, in a future situation, we may not have the services of sealift for a period of time? What would happen if the United States were entering a land-locked region or if a key seaport were suddenly incapacitated?

The availability of ample sealift has been a continuing assumption in the ongoing process of determining mobility requirements. This is an important issue, because, when sealift is available, the DoD's MIDAS model selects sealift for moving most of DoD's units that have large amounts of outsize materiel. With sealift amply available,

MIDAS probably is making the wisest choice in applying resources to most effectively move forces to the theater.

The problem with basing the airlift force structure on the assumption that sealift is available is that it appears that the amount of outsize materiel that must be moved by airlift is relatively small, as was the case in the Gulf War airlift.

So, to provide a tougher but still plausible test, we assumed that sealift, for the period of interest, would not be available and that a representative mix of DoD units would nonetheless still need to be deployed and sustained. To measure performance of the airlift system, we examined the average daily delivery rate for the period of interest. Alternatively, we could have measured the time to close a fixed amount of loads. For the complete movement of the divisions of interest, we did calculate closure times. Generally, however, the options were sized to provide comparable levels of performance. The most interesting difference among the options was cost.

As a surrogate for a representative mix of DoD units, we turned to the Service that uses the most airlift and that requires the greatest proportion of that airlift to be in the form of outsize materiel. That service is the Army. The Army Fellows at RAND and the Army staff were in a position to provide necessary data to support our analysis. Obtaining data in our required form was more problematic for the other Services, because we were unable to find such information in a readily available form.

To move a representative mix of the Army's combat units, we selected all five of the Army's five rapid-deployment divisions existing at that time.¹⁶ To simplify the analysis, we did not include the combat support (CS) and combat service support (CSS) units that are required in addition to the combat divisions. Although the total amount of material that has to be moved for the CS and CSS units is comparable to that of the combat units that they support, the overall proportion of outsize materiel is not as large as that of combat units.

The Army provided its assessments of how many C-5 missions and how many C-141 missions would be required for each battalion-level

¹⁶See Table 4.1 in Volume 2.

unit. We treated all of the loads that the Army designated for movement on C-5 missions as outsize-mission loads and allowed such loads to be moved only by outsize-capable transports (C-5 or C-17). Similarly, we designated all of the loads that the Army designated for movement on C-141 missions as oversize-mission loads and allowed such materiel to be moved only by oversize-capable transports (C-5, C-17, C-141, and to a limited extent, the 747-400F).

Although we sought required delivery schedules for the units with the idea that the initial arriving units would be prepared to enter into combat, we learned that units are not organized for such a phased entrance into combat; consequently, such schedules were unavailable. Nonetheless, we constructed our own order of delivery to simulate such a possibility and tested each option's ability to deliver the leading units for each division during the initial weeks. (See Topic 14.)

Regarding the matter of bulk cargo (actually 463L-palletized materiel), pallets are moved on logistics support missions (including resupply and sustainment materiel) in addition to unit deployment missions. Unfortunately, Gulf War databases have not provided us visibility on the percentage of materiel that was moved on 463L pallets for each mission. For example, the MAIRS database that AMC provided does not show the number of pallets that were moved on each unit deployment mission.

It is reasonable to assume, however, that logistics missions nearly exclusively moved 463L pallets (hence "bulk"). AMC has used such an assumption to make an estimate of the amount of bulk cargo moved by airlift for the Gulf War. To do this, it sorted the Gulf War airlift missions into unit deployment missions and logistics support missions. It estimated that half (48 percent) of the materiel moved the first 30 days by airlift was in the bulk (463L palletized materiel) category. Later, that proportion climbed to 74 percent; during the peak months of the airlift (December and January), it was 63 percent.

For our closure-time calculations, we assumed that, in addition to the outsize-mission materiel and the oversize-mission materiel, there would be a category of bulk-cargo mission loads, the total weight of which would be equal to that of the outsize- plus oversize-

mission loads. That is, 50 percent of the total weight of all mission loads would be in the form of bulk cargo.

Toughness of the Scenario's Load Mix

To ensure that each option could handle a tough mix of loads, our scenario requires 23 percent of the materiel to be sent on an outsize-capable transport. The information we have for the updated Mobility Requirements Study (see Topic 14) is that 15 percent of the materiel is outsize during the first 30 days, and the percentage declines thereafter.

Approach to Characterizing the Scenario's Load Mix

By involving the airlift user in the process of assessing the number of missions required to move battalion-level units, we have treated the movement of specific units and have avoided having to make assumptions about how those units might organize their loads. Most airlift research efforts, however, use models to approximate unit-level decisions about how they would organize their loads and hence what mix of outsize and oversize transports they would need.

The mix of loads called for in our research scenario provides a tougher and more enduring test of the merits of alternative airlift fleets than do traditional analyses that use the DoD's estimate of the official requirement. It is tougher because outsize materiel accounts for a higher percentage of the cargo. It is more potentially enduring because it uses a hypothetical scenario rather than an official requirement that may quickly become dated.

Moreover, unlike most other research efforts, mission loads for unit deployments were obtained directly from the airlift user; thus, our mix of airlift loads involves fewer assumptions about how aircraft loads might be arranged. Overall, we believe that the mix of loads used in our research scenario provides a reasonable research context for ensuring that the preferred fleet mix provides a reasonably robust range of capabilities for handling the uncertain spectrum of future needs for strategic airlift.

AIRLIFT DELIVERY TIMELINES

The in-theater arrival times for airlift deliveries are influenced by the demands for airlift services and the capacity of the airlift system. The capacity of the airlift system is determined by the mix of transports (and crews) that are available and the mix of airfields that are available. Thus, assumed strategies for using air bases in deploying units, as well as the manner in which peak load conditions are represented in the analysis, are important aspects of the research context.

Parallel Delivery Streams (Topic 13)

Our research scenario is based upon the use of parallel delivery streams to link multiple APODs to multiple APOEs. The concept of multiple delivery streams (including parallel streams) is supported by the experience of the Gulf War airlift. Where multiple delivery streams were used, congestion was averted at most APOEs and APODs. Moreover, further application of the concept may relieve some of the congestion that was observed at both APODs and APOEs.

The research results of Lund, Berg, and Replogle (1993) show that many different pairs of APOEs and APODs were used to deploy and support forces for the Gulf War. Although Dhahran was the APOD for 59 percent of the airlift missions the first month, and 37 percent during the peak month, many other APODs were also used (Jubail, Riyadh, King Fahd, Bahrain, etc.). Many different APOEs were also used. Moreover, in the instance of the Air Force, certain pairs of APOEs and APODs were served by many airlift missions. Thus the idea of parallel delivery streams was also demonstrated.

The Army, however, mostly deployed one division at a time, and the APOD of choice was mostly Dhahran—the busiest APOD. The movement of the Army took longer than it needed to, because many more transport aircraft were available than the Army could load at the single APOE used for deploying the 82nd Airborne Division.

Satisfying Demands for Airlift During Peak Periods (Topic 14)

Because the airlift demands during peak periods, and the manner in which they are represented, can have a significant influence on the comparative analysis of fleet options, it is useful to review the periods

analyzed, the methods applied, the assumptions used, and how our approach may differ from those used by other analysts.

Our approach to evaluating fleet options focused on the most demanding period, applied tools consistent with prevailing practices, and aimed to ensure that, of the options analyzed, the preferred fleet mix would provide the most cost-effective satisfaction of DoD's evolving needs for airlift.

Periods of Highest Demand. Of the various periods in a major airlift, it is during the first 30 days that the demand for outsize airlift usually represents the largest percentage of that load, as was the case during the Gulf War airlift (where AMC estimates it was 10 percent of the cargo delivered by airlift). Thus, for the closure-time calculations, we used assumptions about the mix of loads that reflect expectations for the conditions likely to prevail during the first 30 days.

We hasten to add, however, that the greatest amount of airlift was actually applied during the sixth 30-day period, with 107,000 tons delivered, in contrast to the first 30 days, with 63,000 tons delivered. During the sixth 30-day period, 63 percent of the cargo was bulk, whereas during the first 30 days, 48 percent was bulk. We also focused on the first thirty days, however, because that is when the greatest percentage of outsize cargo is expected.

Research Tools Applied. Like many others, we used steady-state models to assess airlift system performance. Our model was applied to a set of assumptions that represents load conditions for the first 30-day period closure-time calculations (Table 4.11 in Volume 2), as well as a peak month condition (Table 4.8).

In addition to discussing our results in terms of average daily delivery rates, we also provided results that show what would happen if the scenario were continued until all five divisions were closed. The resulting closure times of 4 to 4.5 months are clearly hypothetical. Since each division comprises three brigades, the reader could divide by three to see roughly what it would take to close a single brigade of each division. Similarly, dividing by six would show the very rough needs (about three weeks) to close half a brigade from each division.

Although closing half a brigade from each of the five divisions over a three-week period is about the kind of deployment chore that airlift

(with no sealift) seems able to handle, the U.S. Army currently does not train, organize, and equip its divisions to field and employ such a cross-divisional force.

Assumptions. As discussed previously, our assumptions for the first 30 days result in a need to move 23 percent of the materiel on outsize-capable aircraft. This contrasts with a Gulf War experience (with 10 percent outsize during the first 30 days) and with DoD's recent assessment that outsize represents 15 percent during the first 30 days of a major regional contingency. In both the Gulf War and in DoD's recent assessments, the heavy divisions (with most of the outsize materiel) are delivered by sealift.

There are ambiguities here, however, about what is included in AMC's estimate of outsize for the Gulf War and DoD's assessment of outsize in its requirement. One interpretation is that each percentage refers to outsize materiel; the other is that the percentage refers to outsize-mission materiel, which is that mix of other classes of materiel (oversize and bulk) that must be loaded along with the outsize materiel either to satisfy the user's needs or to make use of available space.

Analysis of the units moved during the first 30 days, combined with analysis of the outsize missions those units require, suggests that the AMC estimates more probably reflect outsize-mission materiel requirements than they reflect the weight of outsize material. Further, AMC cautioned us to not interpret its estimates too precisely, because they were not calculated from data files established for such a purpose. Rather, their estimates were based upon a best-effort reconstruction of what loads probably were like.

The DoD's requirements database that the Air Staff asked us to examine (provided to RAND during March 1994) does not define precisely what is included in the term "outsize load." Neither does the database identify the unit or its actual APOE, because most of the loads for the entire deployment have been assigned Tinker AFB as their APOE. Generally, DoD's MIDAS model has represented all of the onload locations (both air and sea) in the CONUS with a few ports of embarkation. It is not uncommon for all of the APOEs in the airlift system to be represented by a single APOE. Thus, we were unable to see whether the 15 percent refers to outsize-mission loads

or strictly to the weight of outsize materiel. Again, however, given the way that MIDAS assigns loads to either sealift or airlift, it is likely that the heavy divisions (with most of the outsize) were assigned to sealift, leaving the light divisions—and perhaps theater air defense (Patriot batteries)—for airlift.

To further test the robustness of the five fleet options that were in our final evaluation,¹⁷ we explored what it would take to deploy Patriot batteries and to deploy those combat units that may need to be the leading units in a forced-entry scenario by the five rapid deployment divisions. Patriot batteries alone did not appear to be a problem,¹⁸ nor did the light divisions (airborne, air assault, and infantry).

Whether the combat equipment for the leading units from the heavy divisions (armored and mechanized) taxes the outsize airlift capacity depends upon how much associated support (and its amount of outsize materiel) must accompany or closely follow to sustain those units in combat. It also depends upon how much fuel and ammunition is prepositioned for those units. The sensitivity analysis showed that, if sufficient fuel and ammunition is prepositioned and if support units are not needed for the first several weeks, 87 percent of Option E's outsize capacity would need to be exclusively applied to delivering outsize-mission materiel, provided that the CRAF had been activated on the first day of the deployment and that the activation provided an amount of airlift equivalent to that provided by the Gulf War's Stage II activation.

However, because units will need some level of support, plus some headquarters elements and other noncombat elements from the divisions, it seems unlikely, even in our scenario, that there would be insufficient outsize capacity during the first two to three weeks.

Differences with the Approaches Used by Other Research Efforts. Analysis of airlift performance for the first 30 days and the use of steady-state models to conduct such analyses are common practices.

¹⁷See Chapter 4 of Volume 2.

¹⁸A Patriot battery with two launchers requires from five to eight C-5 missions plus additional missions by aircraft that do not need to be outsize-capable transports. For an eight-launcher battery, the number of C-5 missions increases to 13. Batteries typically have four to six launchers each. Depending upon the threat, about a dozen batteries may be needed for a regional contingency.

Regarding the representation of bulk cargo, research subsequent to ours (based upon DoD's recent estimate of requirements for the first 30 days) has been assuming that bulk cargo would represent as little as 25 percent. At such levels, the Option E fleet would see most of the 747-400F transports used in our scenario carrying oversize cargo, assuming CRAF activation at the Gulf War's Stage II level. Under this condition, the average payload for 747-400F missions would be 35 percent lower than for bulk-cargo missions (see Topic 27).

However, because we have not yet had the opportunity to review the data and methods that DoD used to form its current estimate of the load mix, we remain to be convinced that the Gulf War data point (half of the cargo was bulk) should be dismissed. Although much attention continues to be placed on the movement of combat equipment, we need to remember that a combat-effective force comprises the right mix of equipment, palletized cargo (bulk), and people. Although palletized (bulk) cargo is more difficult for analysts to track and model, it is still just as essential to a combat unit as the vehicles that are easier to track and model.

AIRCRAFT MODIFICATIONS AND OPERATIONS

Comparative analysis of alternative fleet mixes can be affected by the assumptions about aircraft modifications, scheduling of aircraft, management of flight crews, and the need to efficiently match loads with aircraft to most effectively apply the strengths of the different transports comprising an airlift fleet mix.

Modifications to the 747-400F (Topic 15)

The merits (and the costs) of placing the 747-400F in the DoD's airlift fleet depend in part on the manner and the extent to which the Air Force might modify the 747-400F design to provide the DoD greater latitude in its ability to apply the aircraft to future needs for strategic airlift.

Although none of the modifications assumed in this research is required to achieve the performance reflected in our analysis of the final five options, the Air Force should consider the marginal costs and

the potential marginal value of adding aerial refueling, a stronger floor, and side doors.

Aerial Refueling. Although aerial refueling could increase throughput by 10 percent, the main benefit may be as a hedge against limitations on the availability of en route bases. If the cost and weight penalties for the 747-400F are small (say a few million dollars and a few hundred pounds per aircraft), this may be a prudent hedge. If the cost exceeds \$5 to 10 million per aircraft, it may be much tougher to justify.

Stronger Floor. Although a stronger floor would increase the amount of oversize that can be carried on the 747, the Air Force needs to assess the costs and benefits of such a modification. If the commercial version of the 747-400F can already carry 50 to 60 percent of the oversize materiel, spending more than a few million dollars per aircraft for floor strengthening may be hard to justify unless the DoD decides that the 747-400F needs to become the principal aircraft for carrying oversize materiel.

Emergency Exit Doors. Unless a policy clearly precludes a 747-400F operated by DoD from carrying passengers, the option of adding emergency exit doors should be explored. If there is a policy precluding such use, it may warrant reconsideration in light of today's airlift needs.

Aircraft Scheduling (Topic 16)

Efficiently scheduling transport aircraft to support a major regional contingency is a major challenge for the U.S. Transportation Command, because both the demands for transportation and the supply of available transports are constantly changing in response to unpredictable events. Consequently, scheduling would be greatly simplified if all of the transport aircraft were equally capable of carrying any mix of loads (outsize, oversize, bulk, and passengers). Thus, the introduction of a transport with a narrow range of load-carrying capabilities (such as the 747-400F) complicates a scheduling task that was shown to be very challenging during the Gulf War airlift.

Moreover, limitations on the command, control, communications, and computer (C⁴) systems that support aircraft scheduling make it

very difficult to effectively apply any airlift fleet comprising fundamentally different types of transports to meet the constantly changing needs and priorities for loads originating at many different APOEs and destined for many different APODs. Such limitations must be addressed and reduced to benefit from the potential economic advantage that a mixed fleet offers. The government has two potential courses of action, as described below. The first of these is already being pursued, although possibly not with sufficient vigor.

Improve Command, Control, Communication, and Computer Systems. Because the cost-saving potential that a mixed fleet offers is far larger than the Air Force's assessment of the cost of achieving needed improvements in C⁴, our report assumes that needed levels of C⁴ performance will be achieved. Further, the dependence upon CRAF to augment military airlift already dictates that the fleet will have mixed types of aircraft. The issue is about the ratio of different types. Clearly, the management challenge escalates as the ratio of civil-style to outsize-capable military-style transports increases, because an outsize-capable transport can deliver any load (deliverable by airlift), whereas the civil-style transport can deliver only certain types of loads.

One of the problems faced during the Gulf War airlift was that the military-style transports often required unscheduled maintenance that would consume time that was difficult to estimate. Aircraft, therefore, were not given their next mission assignments until maintenance was completed, or nearly so. Because scheduling was done at periodic intervals, aircraft ready for a mission would at times wait on the ground until the next round of mission assignments was established.

In our analysis, we permanently assigned aircraft to specific mission cycles, much as a bus company will assign a bus to a single route for the course of a day.¹⁹ Such "perfect" scheduling is impossible for the current C⁴ system and will be a tough goal for an improved C⁴ system.

¹⁹Thus, as soon as maintenance on an aircraft is completed, the aircraft can be returned to duty rather than wait for the next schedule to be issued.

Simplify the Airlift Problem. Instead of C⁴ improvements, or in addition to such improvements, the government may find it appropriate to simplify the strategic airlift management problem by reducing the number of APOEs served from the hundred or so now anticipated for a major conflict to a handful (perhaps five to ten) of major regional airlift loading centers.

Rather than buy and operate additional aircraft to compensate for inefficient management of resources and rather than buying versatile aircraft capable of carrying all types of loads to compensate for inefficient application of airlift resources, it seems that the nation would obtain far greater airlift capacity from its investments with improved management of the airlift system and perhaps streamlining of the system to serve fewer APOEs. Of course, reducing the number of APOEs would reduce the convenience of airlift for units that would no longer have a nearby APOE. However, because many units already travel significant distances to an APOE, convenience alone may not be an overriding consideration.

Management of Crew Changes (Topic 17)

In view of the large number of APOEs and APODs that are used to support a major airlift, such as that for the Gulf War, AMC faces a major challenge in trying to adopt a policy of changing air crews (including aerial refueling qualified crews) at APOEs and APODs, as is assumed in our analysis, instead of the current AMC practice of changing crews at en route bases and at AMC's major home bases.

There are three reasons for considering new policies in this area. The first reason is to increase the productivity of the military-style transports, especially the C-5, by reducing wear on high-maintenance systems through minimizing the number of landings and takeoffs required to complete a full mission cycle from an APOE to an APOD and finally back to an APOE (perhaps after a needed stop for maintenance at a home base). The second reason is to increase the productivity of the military airlift fleet by using the existing fleet of tankers to provide aerial refueling for transports. The third reason is to realize the productivity potential of the 747-400F by exploiting its capability to fly very long distances.

To pursue any of these three interests, the AMC would have to alter its current policies governing the changing of flight crews. Because our research found interesting opportunities for increasing productivity, such policy changes seem to warrant serious consideration.

Benefit of Avoiding a Stop on Each Mission Cycle. Avoiding a stop reduces flight time if the stop is not along the route that otherwise would be flown. Even if it is along the route, the stop reduces flight time by avoiding the deceleration during descent and acceleration after takeoff. Moreover, it reduces ground time in several ways. First, it avoids time spent taxiing and time spent waiting for takeoff. It avoids routine servicing and inspection that occurs every time a plane stops. It also reduces wear and, therefore, the time required for unscheduled maintenance, a matter of major significance for past military-style transports. Analysis of these considerations raises serious questions, in our view, about the efficiency of adding one or more stops to a mission cycle just to change flight crews.

Benefit of Aerial Refueling. Aerial refueling can significantly increase the throughput of military-style transports (by about 30 percent) only if flight crews can be changed at the APOEs and APODs. With improved C⁴ to help manage both flight crews and aircraft schedules (and perhaps a reduction in the number of APOEs), and with the use of other types of aircraft to position flight crews when necessary, the DoD could increase the daily deliveries by its airlift fleet.

Efficiency of Matching Loads to Aircraft (Topic 18)

For assessing the comparative performance of alternative airlift fleets, the approach for determining the mix of loads for airlift missions is important to calculating the number of outsize-capable transports required.

Past research has relied upon models of the user's process for loading aircraft. Our approach relied on user estimates of mission needs. While one approach relies upon the accuracy of the user's estimates, the other approach relies upon the accuracy with which the model's methods and assumptions estimate the user's process of preparing loads for airlift missions.

Model Assignment of Loads to Transports. Past research efforts have used the model assignment approach. They either treated loads in a more aggregate fashion (such as total tons of outsize materiel for a division) or used loading models to represent how the user might prepare loads for individual aircraft. These research efforts have represented the mix of load types on outsize-capable aircraft by assuming fixed limits to the percentage of each aircraft's load that can be in the form of outsize materiel rather than nonoutsize. Such assumptions, if set too high or too low, can end up distorting the needs for outsize-capable transports. For example, if one assumes that each outsize-capable transport can only carry such a small amount of outsize materiel that the average outsize load amounts to, say, only one-fifth of the total average load, in some situations there may not be enough outsize-capable transports available, because the outsize loads have been spread so thinly. Thus, a serious hazard of this approach to representing loads is that, compared to the way that units can actually organize their loads, loading models can cause the outsize materiel to be spread too thinly, or aggregated too greatly on too few transports.

The assumption of a fixed percentage limit, and the low levels for that limit that seem to be used by AMC, appears to conflict with what we have seen in the user's estimates of individual battalion needs. For example, for the two heavy divisions (accounting for 93 percent of the outsize airlift missions for five divisions), the majority of the missions move very heavy items of equipment, and a single item of equipment often accounts for most of the allowable load.

Furthermore, as part of our sensitivity analyses, we had the Army prepare load plans for deploying Patriot batteries with two to eight launchers per battery. The weight of the outsize materiel accounted for 48 to 66 percent of the maximum aircraft cabin load of 130,000 lbs used in those analyses.

User Assignment of Loads to Transports. Our research used the user assignment approach for determining what loads had to go on specialized transports, such as the outsize-capable transports. We did this by considering airlift needs at the battalion level and by using the airlift user's estimates for the number of missions requiring outsize-capable aircraft for each battalion. Because the organization of loads

for transportation is done by each unit to satisfy its needs, and because unit needs vary widely within a division and across different types of divisions, it is not practical for a model to address all of the significant considerations that enter into each unit's decisions about how it will organize its loads for transportation.

THROUGHPUT RESEARCH

The major parts of the throughput research include our approach to consideration of other civil-style transports, our approach to comparative analysis of aircraft demands on air base infrastructure, the average payloads we used in the analysis, our representation of aircraft utilization rates, aircraft block speeds, and our approach to the throughput calculations.

APPROACH TO CONSIDERATION OF OTHER CIVIL-STYLE TRANSPORTS (TOPIC 19)

Although bulk cargo accounted for half or more of the materiel delivered by air during the Gulf War airlift, other airlifts in the future may not need the delivery of that much bulk materiel. Thus, we assumed that a civil-style transport operated by the DoD should have the capability to carry a large proportion of the oversize cargo, as well as bulk cargo, provided that such a requirement did not come at too great a price. A screening of the options quickly yielded the 747 freighter as a chief candidate from the vantage points of both capability and cost.

As discussed in Volume 2, Chapter Three, economies of scale and the commercial experiences of the world's air carriers have demonstrated that the 747 freighters are the most economical transport on routes that have high volumes of cargo that need to be moved over long distances. Further, the 747 freighter was the civil-style transport

of choice by the CRAF program office during the Gulf War airlift.¹ Moreover, of the civil-style transports, the 747's large cabin gives it the greatest capability to carry oversize cargo. These considerations would seem to justify the selection of the 747 as the chief candidate from the civil transport arena.

APPROACH TO THE COMPARATIVE ANALYSIS OF AIRCRAFT DEMANDS ON AIR BASE INFRASTRUCTURE

Two fundamentally different approaches are available for making comparative analyses of aircraft demands on air base infrastructure:

- **Method of Explicit Constraints.** This method uses explicit constraints that allow support resources and air base facilities to limit the performance of the airlift system. Whenever the use of a resource reaches the limit set by the assumed constraint, the flow of transports is reduced so that demands for that resource do not exceed the assumed limit. This means that some aircraft are in effect grounded and are not allowed to participate in the airlift.
- **Method of Resource Impact Assessment.** This method tabulates the use of infrastructure resources and reports both total use and base-specific use. Where a base's capacity for a resource or facility is exceeded, the method identifies the extent to which the base's capacity has been exceeded. This method does not ground any aircraft.

Whether it is reasonable to assume that transport aircraft would actually be grounded during a major emergency rather than find additional routes and more airfields in the theater or en route is arguable, given the number of airfields in the world today. The method of explicit constraints, though, is quite firm in the application of its constraints. Once a constraint is reached, aircraft are grounded until the flow is reduced to satisfy the binding constraint. Because of the guillotine effect of explicit constraints, great care and attention should be used in setting the values of the constraints and monitor-

¹This point was acknowledged by the staff of the CRAF program office and was demonstrated through the use of 747s whenever they were available. See Chapters Two and Three of Volume 2.

ing the results to ensure that the constraints do not end up limiting system performance in unrealistic or unreasonable ways.

A further complication arises from the choice of bases and routes used for the airlift analysis and whether or not aerial refueling is used. With the method of explicit constraints, the grounding of aircraft makes the results very sensitive to the number of APOEs and APODs that are used in the analysis, as well as the values assumed for the MOG constraints that limit the number of aircraft that can be parked on the ramp at any given time. With the method of resource impact assessment, aircraft are not grounded, and the throughput results are much less sensitive to the values assumed to represent the needs for support resources and airfield facilities. We examine each of these methods more fully below.

The Method of Explicit Constraints as the Way to Represent Infrastructure Considerations (Topic 20)

The method of explicitly constraining the flow of transports at air bases is a very appealing approach with a lot of long-term potential. However, it is not the only approach to representing infrastructure considerations in an analysis, and because of limitations on its current implementation (which we are about to discuss), it may not be the most appropriate method at this time.

Ramp space has been the resource category receiving the most attention for a couple of reasons. First, at busy airfields, ramp space is often a resource in high demand. Second, because the C-17's relatively small size and its novel thrust reversers mean that it needs less ramp space for maneuvering on the ground than other transports, airlift analyses need to address the different needs that alternative transports have for ramp space. The trend has been to use the method of explicit constraints to represent ramp space considerations. Some analyses have also addressed the matter of the availability of air crews.

Interest in representing the use of ramp space was increased by early assessments of the Gulf War airlift. Transports had to wait at en route airfields before proceeding to the theater because high-use APODs had to limit the number of transports arriving each day. It has long been the prevailing wisdom that the daily arrival limits were

caused by limits on the amount of ramp space available for airlift operations. The current Air Staff's view, however, is that the cause was limitations on the ability to refuel transports. Although others over the last couple of years have expressed similar views, we have been unable to find any data or analyses that address this matter. If, contrary to the prior prevailing wisdom, the current Air Staff's view is more nearly correct, the use of ramp space constraints in recent research is not supported by the Gulf War experience.

In theory, each airfield's attributes (ramp space, airfield's daily refueling capacity) and each resource type (fuel trucks, materiel handling equipment, etc.) should be explicitly modeled, and a constraint should be used to represent the capacity for each attribute or resource. In practice, this has not yet been done. Instead, all of the air base resource and facility considerations have been wrapped up in a single variable known as the maximum on ground (MOG) parameter. The constraint on this parameter, though, seems to be determined mostly by consideration of ramp space. Also, it seems that the relative MOG attributes assigned to specific transports have been based exclusively on considering ramp space needs.

Thus, there are many reasons for concern about using the method of explicit constraints at this time:

- **Need for Close Attention.** Because constraints have a guillotine effect (grounding of aircraft) on the parameter being constrained, close attention to details is required. The value of the constraint should be carefully established, as well as the values of the parameter that are assigned to alternative transports. The effects of the parameter on system performance also need to be closely watched, especially when there may be alternatives for relaxing the constraint that may not be represented in the model. For example, larger ramps might be constructed or additional airfields might be used.
- **Incomplete Information.** Our knowledge and databases for specific airfields lack the precision to allow careful determination of the airfield limitations that would prevail during a major airlift for each of the key attributes (ramp space, daily refueling capacity) and key resources (fuel trucks, materiel handling equipment, ground support equipment).

- **Use of MOG as the Single Aggregate Parameter.** Wrapping all of the infrastructure considerations at an airfield into a single measure creates a logically impossible situation for performing legitimate arithmetic, because it becomes nonsensical to add MOG values for different types of transports. Transport A may need lots of ramp space but little fuel, whereas transport B may need much less ramp space but a lot more fuel. Moreover, the resource driving the assigned MOG value at the airfield may be the number of pieces of materiel handling equipment, so both fuel and ramp space considerations would be irrelevant at that airfield.
- **Lack of Standards for Assessing MOG Values.** The Air Force has yet to lay down a set of standards for calculating MOG values and for performing MOG arithmetic.
- **Lack of Approved MOG Planning Factors.** The Air Force has yet to publish approved MOG planning factors for specific transports and specific airfields.

The bottom line is that the method of explicit constraints, as it has been applied thus far with the MOG concept, is not yet ready to consider more than a single dimension of airfield infrastructure at a time. But even focusing MOG on ramp space ignores fuel considerations, which some view as the real pacing constraint during the Gulf War airlift.

We chose to take a different approach (see Topic 22) so that we could assess the needs for ramp space, fuel, and ground support equipment separately. However, a disadvantage of our application of the resource impact assessment method is that it may appear that an analysis has assumed a robust en route system and ignored realistic constraints, such as materiel handling equipment, that are encountered daily in airlift operations. It also may seem that the daily competition between aircraft for such resources as fuel and ramp space have been ignored.

Such matters, however, were addressed with a less ambitious but more explicit method of assessing the impact of operations on the use of resources and facilities that may be limited. To the extent that resource limits might be seriously violated, it is incumbent upon the analyst to modify the scenario or the concept of operations. This was

done on many occasions. For example, such modifications produced our operating concept of using multiple delivery streams to deploy the Army's units more rapidly.

Influence of Multiple Delivery Streams and Aerial Refueling on Infrastructure (Topic 21)

A benefit of multiple delivery streams is the relaxation of congestion at air bases. As discussed previously, multiple streams were often used during the Gulf War airlift, with the exception of the deployment of the Army's units. Demands on the infrastructure at selected air bases can be reduced by using multiple delivery streams and aerial refueling. For example, aerial refueling of transports as they enter and depart a theater can reduce the demand on theater fuel supplies and the time on the ground at APODs. Tankers, of course, would need to be based near the theater.

In our analysis of the final five options, only Option D included aerial refueling. All options, however, used five parallel delivery streams, which minimized the potential for congestion. If we had used fewer APODs and had increased the operations at one of the APODs to match the maximum daily arrival rates maintained for a month at the Gulf War's busiest APOD (Dhahran), there would have been about 41 transports arriving daily. If each transport was unloaded and refueled according to planning factor timelines, an average of only five transports would be parked at the airport. So, on average, only five parking spots would be needed at the busiest APOD. It is highly doubtful that limitations on the availability of ramp space could have caused the limitation on Dhahran's daily ability to receive transports.

On the other hand, if the daily allocation of fuel at Dhahran for transports or the number of fuel trucks for refueling aircraft was the binding constraint, there could easily have been a long line of transports waiting for fuel. Indeed, it is possible that not enough ramp space may have been allocated for all of the transports waiting for fuel. But in such a situation, the binding constraint is not ramp space but fuel. No amount of additional ramp space can relax the fuel constraint. More fuel must be delivered to the airfield; the airfield's storage capacity must be increased to handle irregularities in

deliveries; or the airfield's refueling operations must be given more trucks, people, nozzles, or whatever the limiting resource is.

This illustrates why it is important for airlift analyses to deal directly and separately with the needs for ramp space and fuel. In our analysis, we found that the needs for parking spaces were actually relatively modest. On average, only about 12 transports would need to park within the theater for unloading and refueling, assuming a steady flow of refueling operations. See Topic 22 for a fuller discussion of ramp space.

Method of Resource Impact Assessment (Topic 22)

Because infrastructure limitations can be caused by a variety of resource types, because they often can be relaxed by changing operational concepts (e.g., use more bases or use more fuel trucks), and because investments in air base resources are very different from the investments in the airlift fleet (both in magnitude and type), one useful way to compare alternative fleets is to estimate and compare their relative demands for air base resources and facilities. RAND used this approach to address several resource categories, including ramp space, fuel, and ground support equipment.

Air bases were considered individually, and the results were aggregated to facilitate the comparisons among the alternative fleets. Even assuming that each ramp parking area was used only 50 percent of the time because of the irregular flow of transports, we found that the total theater's need for ramp space amounted to only 2.3 to 2.6 million sq ft, depending upon the option. (Option A needs 2.34 million sq ft, whereas Option E needs 2.48 million sq ft.) In these calculations, the C-17's relatively small size and its superior ground agility were accounted for by assuming that eight C-17s could use a 500,000 sq ft ramp, whereas only three C-5s could use the same amount of ramp space. Although it is probably unreasonable to park that many C-17s so closely on a single ramp, we adopted this Air Force planning factor to give the C-17 credit for being able to make use of small areas that other transports could not.

A military-style transport can unload without the use of any materiel handling equipment (MHE). However, by using MHE, the Air Force can significantly reduce the time and personnel required to unload

and position pallets delivered by military-style transports. For example, the new 60K loader can unload several pallets at a time and take them directly to the pallet yard. Such equipment is essential to efficient unloading at busy APODs. That same piece of MHE will be used to unload the pallets delivered by civil-style transports. Thus, for efficient operations at busy APODs, all transports need MHE to unload pallets. The civil-style transports, however, need MHE for all loads. Moreover, the civil-style transports generally need more ground support equipment, including MHE. To provide a measure of the demands on ground equipment that would be required for the civil-style transports, we compared the options in terms of the daily number of civil-style transports arriving in theater. Again, these results were determined by individual bases and then aggregated to facilitate the comparison among options.

Regarding fuel, which may have been the binding constraint in theater for the Gulf War airlift, we found that Option E had the lowest need for fuel because of the efficiency of the civil-style transport.²

A next logical step in the evolution of this resource impact assessment approach would be to calculate the support equipment requirements at each base in the network.

AVERAGE PAYLOADS USED IN THE THROUGHPUT ANALYSIS

The average payloads used to represent the comparative capabilities of alternative types of transports are one of the most significant variables in the calculation of fleet throughput.³ These payloads vary widely for different aircraft, and the average values are often very sensitive to distances flown, headwinds, and the density of loads.

We defined specific routes for the movement of each division that reflected the prevailing practices and thinking at the time of the research. The maximum critical leg length for most of the routes used by the military-style transports was about 3,500 n mi (plus or minus a

²In our analysis, we assumed that the engines on the 747-400F would be calibrated to use the same fuel as the military-style transports.

³See Figure 4.18 in Volume 2.

couple of hundred of miles) for the movement of each division. Because the deployment is eastward, we were able to assume that there were no headwinds for route planning. For a westward deployment, we would have based route planning on an assumed headwind of about 70 kts.

Air Force Pamphlet 76-2 (Topic 23)

Air Force Pamphlet 76-2, last revised May 29, 1987, is the Air Force's most comprehensive document for a wide variety of factors that enter into the calculation of throughput for an airlift fleet.

Because of its expressed purpose to provide broad airlift planning factors for peacetime and wartime, we considered AFP 76-2 a reasonable source for information.⁴ There is no other official source on airlift planning factors. Moreover, AFP 76-2 uses consistent ground rules and assumptions to calculate planning factor values for alternative transports. For example, the average payloads for oversize cargo missions were determined for each type of transport by the Air Force using the same model, the same assumptions, and the same database for the units being deployed. The database represented the movement of a large Army force consisting of a variety of unit types.

Average Payload Performance for the C-5 (Topic 24)

For the C-5 fleet, the throughput analysis used an average payload of 130,200 lbs for a 3,500 n mi critical leg. This payload was obtained from AFP 76-2 for the condition of a 3,500 n mi flight distance with no headwind and assuming a cargo of oversize materiel. For outsize materiel, the planning factor payload in AFP 76-2 is 133,000 lbs. In our analysis, most C-5 missions carried oversize materiel or a mix of oversize and outsize.

The 130,200-lb payload from AFP 76-2 used in our analysis is a bit higher than the actual payloads carried during the Gulf War, where

⁴AFP 76-2 was used except where subsequent research has demonstrated more appropriate planning factors. For example, ground time planning factors had been updated by AMC as reported in their analysis of the Gulf War airlift (Ewing, 1991). Also, instead of using planning factors, aircraft utilization rates were determined with a model.

monthly averages for C-5 payloads were 120,600 lbs during the first month and 126,600 during the peak month. Over the first six months, the average monthly payload was 123,300 lbs (5 percent below the 3,500 n mi planning factor). Critical leg lengths varied from 3,000 to 3,850 n mi for the C-5, with most routes having a critical leg length of about 3,500 n mi plus or minus a couple hundred miles.

Average Payload Performance for the C-141 (Topic 25)

For the C-141 fleet, the throughput analysis used an average payload of 49,000 lbs for a 3,500 n mi critical leg. This payload was obtained from AFP 76-2 for the condition of a 3,500 n mi flight distance with no headwind and assuming a cargo of oversize materiel. For bulk materiel, the planning factor payload in AFP 76-2 is 53,200 lbs. In our analysis, most C-141 missions carried oversize materiel; some missions carried bulk.

The 49,000-lb payload used in the throughput analysis is about 23 percent higher than the actual payloads from the Gulf War. Critical leg lengths during the Gulf War airlift varied from 3,000 to 3,900 n mi for the C-141. Most routes had critical leg lengths of about 3,500 n mi. Through the course of our research and documentation phase, various explanations have been offered for the shortfall in C-141 payloads, including structural fatigue problems. However, the shortfall is not a significant issue for the comparison of alternative fleets, because the same number of C-141s was assumed to be present in each fleet.⁵

Average Payload Performance for the C-17 (Topic 26)

Because the C-17 is not covered by AFP 76-2, we based our calculations of the C-17 payload upon (1) the AFP 76-2 payloads for the C-5 and C-141 for a critical leg length of 3,500 n mi and (2) the assumption that the load per square foot of floor area would be approximately the same for the C-5, C-141, and C-17, because each aircraft's

⁵Any errors in the estimated payload for the C-141 would equally affect each option, because the number of C-141s was held constant.

payload for a 3,500 n mi distance is limited by available floor space rather than range performance.

For the C-17 fleet, the throughput analysis therefore used an average payload of 74,800 lbs for a 3,500 n mi critical leg. For a 3,500 n mi flight distance with no headwind and assuming a cargo of oversize materiel, both the C-5 and the C-141 have average cargo densities that yield 47 lbs of load per sq ft of cargo cabin floor area (including ramps). We assumed that the C-17 would realize the same average cargo densities, because it would be carrying similar materiel and because the resulting payload was then within the performance capabilities of the C-17 for a 3,500 n mi flight distance assuming no headwind.⁶ At the time of publication in late 1994, it appeared that the maximum payload for that condition may be in the neighborhood of the 74,800-lb average payload (although, perhaps, 5,000 lbs lower) depending upon various modifications in process or being contemplated. At the time of the research (1992), the maximum payload for the condition of interest was 91,000 lbs. If the maximum payload actually ends up at the lower value, the routes used in the throughput analysis would need to be modified to include more stops. Such modifications would increase flight distances and ground time for a given mission cycle and would reduce the calculated throughput for a C-17 fleet.

In theory, C-17 payloads might be increased by assuming higher-density cargo and by adopting either alternative routing with shorter critical leg lengths or aerial refueling. Such assumptions, however, would also need to be applied to the other transports. Moreover, the 3,500 n mi distance is representative of the critical leg for the actual missions flown for the Gulf War airlift.

DoD's COEA for the C-17 used an average payload of 96,600 lbs, based upon aircraft loading analyses. See Topic 18 for aircraft loading analyses and Topics 56 and 61 for additional discussion of the COEA.

⁶Recent analyses by the DoD for a critical leg length of 3,200 n mi show the C-17 with a 15 percent higher average deck load than the C-5 and the C-141. For the longer critical leg lengths applicable to a deployment to Southwest Asia, we would expect a smaller difference.

Average Payload Performance for the 747-400F (Topic 27)

The average payload performance for the 747-400F varies from as high as 249,000 lbs to as low as 117,000 lbs, depending upon the mix of bulk and oversize cargo that is carried and how the bulk cargo is packed. The high payload pertains to the case in which only bulk cargo is carried and is packed on commercial pallets (or in commercial containers). The low payload applies when only oversize materiel is being moved (there is no bulk cargo to be moved).

Missions with only bulk cargo tend to be logistics missions that are moving supplies. Missions with oversize materiel tend to be unit deployment missions in which a mix of cargo (outsize, oversize, and bulk) and personnel is being moved.

Bulk Cargo Missions, Average Payload. For the 747-400F fleet, our analysis used an average payload of 223,200 lbs for a 3,500 n mi critical leg when carrying bulk cargo. This payload was obtained from AFP 76-2 for the condition of a 3,500 n mi flight distance with no headwind and assuming a cargo of bulk materiel being carried by a 747-200F. Compared to the 747-200F, the 747-400F has up to 1,777 cu ft of additional usable volume (a 7-percent increase to 27,747 cu ft), depending upon how the cargo is packed. It also has a greater range capability.

The average payloads in AFP 76-2 are based on the assumptions that (1) bulk cargo has an average density of 8.75 lbs per cu ft; (2) all bulk cargo is carried on the 463L pallet, rather than on commercial pallets or in commercial containers; and (3) an empty 463L pallet weighs 354 lbs and uses 2.25 inches of the available vertical height. Loads carried by the 747-200F and -400F have vertical limitations of 96 inches for the seven pallet positions up front, 118 inches for the 30 positions behind the flight deck, and 64 inches for the nine positions in the lower lobe. Using the AFP 76-2 factors for load density and pallet characteristics, the resulting loads per pallet (including pallet weight) are 4,600 lbs (96 in. height), 5,430 lbs⁷ (118 in. height), and 3,150 lbs (64 in. height). Pallets loaded behind the flight deck must be contoured to accommodate the curvature of the fuselage. Some

⁷We assumed that contouring reduces the usable volume by about 3 percent, based upon the experience of commercial pallets and containers.

commercial operators find it convenient to use containers that are shaped to provide easy use of the available volume. Given that 37 463L pallets are loaded on the main deck and nine are loaded in the lower lobe, and assuming that 30 of the pallets can be loaded to a height of 118 inches, we estimate that the average payload for a 747-400F is 223,450 lbs.

Because commercial pallets or containers better conform to the interior geometry of the 747-400F, average payloads could reach 249,000 lbs based upon the cargo density of 8.75 lbs per cu ft. Moreover, an additional 7,000 lbs of loose bulk materiel could also be loaded, bringing the average payload to 256,000 lbs. At such a payload (which includes the weight of pallets and containers), the 747-400F could fly a 4,300-n mi mission.

Note, however, that our analysis is based on the assumption that all cargo must be loaded on 463L pallets.

Oversize Cargo Missions, Average Payload. For oversize materiel, the planning factor payload in AFP 76-2 is 145,000 lbs for a 747-200F. The 747-400F has an unobstructed rectangular floor area measuring approximately 140 ft by 18 ft that is well-suited for carrying oversize materiel.⁸ This provides 2,512 sq ft of floor area that is well-suited for oversize. In addition, there are three more pallet positions on the main deck and nine in the lower lobe. Most of these pallet positions (except two on the main deck) could carry oversize materiel as well. However, these 12 pallet positions probably are best suited for carrying bulk cargo. Using AMC's planning-factor cargo densities and pallet weights for the 463L pallet, we calculated that these 12 positions would account for 46,800 lbs of payload.

Assuming that oversize was carried on the main deck only, as described, and that bulk cargo would be carried in the 12 positions identified, the planning factor payload of 145,000 lbs suggests that 98,200 lbs of oversize cargo would be carried within the 140 ft by 18 ft rectangle. The average floor loading would have to be 39 lbs per sq ft ($98,200/2,512$). We have had the opportunity to examine an analysis by the 747-400F contractor that indicates that such floor loading is achievable for an equipment list that they were asked to evaluate for

⁸The C-17 cabin deck (including the ramp) measures 88 ft by 18 ft.

DoD during late 1993.⁹ Thus, the AFP 76-2 planning factor for oversize cargo loads appears reasonable for the 747-200F (and 747-400F), provided that about one-third of the cargo weight is actually accounted for by bulk cargo placed in the 12 identified positions.

Increasing the amount of oversize is possible by carrying cargo that will fit in the lower lobe. The 747-400F contractor estimates that doing so would increase the possible percentage of oversize cargo to 85 percent for the same equipment lists. The average payload would decline to 137,000 lbs, however. The 137,000-lb payload does not include the weight of pallets (or chains), which amount to about 9,000 lbs, because such pallets would not be used on the military-style transports for vehicular equipment; moreover, bulk cargo can be loaded on trucks and trailers. There is less opportunity for such loading on the 747-400F because of the 8-ft height limit for the nose door through which most oversize cargo would be loaded.

In addition to the average payload, there is also the matter of how much of the oversize materiel for a specific deployment that a 747-400F could deliver. Analysis results for this matter have varied widely over the years, depending upon the equipment list used, the type of trucks in the list, the configuration of the trucks (loaded, unloaded, cabs collapsed or not collapsed, etc.), the strength of the 747's floor, and the sizes of the 747's doors. We have seen results ranging from as low as 33 percent to as high as 85 percent, depending upon the assumptions used in the analysis.

Missions with Mixed Loads of Bulk and Oversize. The Air Staff reports that DoD has modeled loads across all time-phased force deployment data (TPFDD) commodity groups and found that the average payload for the 747-400F would be 146,200 lbs. (The DoD's COEA used such a payload.) Because we have not had the opportunity to examine that analysis, we don't know if palletized cargo was included and, if so, how much of the total weight was bulk materiel and oversize.

Using these planning factors (and loading bulk on 463L pallets), the average payload varies depending upon what portion of the oversize-

⁹The equipment list did not include palletized cargo.

suitable main deck area (the 140 ft x 18 ft rectangle) is used to carry oversize as follows:

- 145,000 lbs, if all of the oversize-suitable area is assigned to carrying oversize (99,000 lbs is oversize materiel)
- 168,000 lbs, if two-thirds of the oversize-suitable area is assigned to carrying oversize (66,000 lbs is oversize materiel)
- 192,000 lbs, if one-third of the oversize-suitable area is assigned to carrying oversize (33,000 lbs is oversize materiel)
- 215,000 lbs, if none of the oversize-suitable area is assigned to carrying oversize.

As discussed previously, carrying bulk on commercial pallets (or containers) instead of 463L pallets would increase payloads:

- 150,000 lbs, if all of the oversize-suitable area is assigned to carrying oversize (99,000 lbs is oversize materiel)
- 178,000 lbs, if two-thirds of the oversize-suitable area is assigned to carrying oversize (66,000 lbs is oversize materiel)
- 208,000 lbs, if one-third of the oversize-suitable area is assigned to carrying oversize (33,000 lbs is oversize materiel)
- 237,000 lbs, if none of the oversize-suitable area is assigned to carrying oversize.

Gulf War Average Payloads for the 747-200F. During the Gulf War airlift, most 747 missions were flown by a variety of configurations that entered service prior to the 747-200F. All carried only bulk cargo. Even over the peak month of the airlift, the daily average number of 747-200Fs supporting the airlift was only about five, with Federal Express averaging several daily, and Northwest averaging one to two daily. Furthermore, some missions were flown by passenger aircraft that had seats removed and plywood placed on the floor. Loading such aircraft by hand reportedly took half a day or more. Other aircraft had cargo floors installed but of varying strengths. Also, some aircraft had 125-in.-high door openings and ceilings (aft of the flight deck), others had 96-in.-high doors and ceilings throughout the cabin.

This meant that the preparation of pallets for 747 missions was problematic because of the wide variation in floor strengths and door heights. Even so, the older 747s (pre-747-200F configurations) and passenger aircraft appear to have performed on average roughly according to the AFP 76-2 planning factors for critical leg distances of 3500 n mi.

The 747-200F configuration was a different story. Federal Express's 747-200F aircraft fell from 13 to 20 percent short¹⁰ of the AFP 76-2 planning factors for the 3,500 n mi critical leg length, according to Air Force records. Federal Express staff recall higher average loads, within about 90 percent of the planning factor. Northwest, the other 747-200F operator at the time, fell about 25 to 30 percent short.

Because most missions were not flown by the 747-200F configuration, it appears that loads were not prepared in such a way as to exploit the stronger floors, higher doors, and greater usable volume of the 747-200F. For example, Federal Express's 747-200F payloads were only slightly higher than those of its other 747s; the same was the case with Northwest's 747s.

Load preparation is the key to fully exploiting the payload and range capabilities offered by the 747-400F. If better load preparation is not practical, the DoD may wish to consider buying the older models of the 747. Used versions are available and can be refurbished at a much lower cost than that of procuring the 747-400F. However, the greater range capability of the 747-400F is a better match for the Air Force's needs for supporting global reach with significant payloads.

DoD's COEA for the C-17 program used an average payload for the 747-400F of 146,200 lbs.

Range Performance for the 747-400F. The range performance for each transport has been adjusted as needed to reflect the Air Force's rules for fuel reserves. Reserves provide for 10 percent of en route time (over water) not to exceed 1 hour of fuel, fuel to reach an alternative airfield in 30 minutes, holding fuel, and fuel for approach and landing.

¹⁰The range of estimates reflects uncertainty about whether the recorded payloads included the weights of the pallets.

REPRESENTATION OF UTILIZATION RATES

Next to average payloads, we found that aircraft utilization rates are the most significant factor affecting the calculation of throughput capabilities for different aircraft.¹¹ Estimation of utilization rates has several important elements: (1) the approach to the calculation, (2) the values used to represent the ground times for loads and/or servicing, and (3) the method used to estimate the ground time for unscheduled maintenance.

Approach to the Representation of Aircraft Utilization Rates

Consistent and realistic analysis is key to an appropriate comparative representation of utilization rates for different types of transports.

Method Used in the Throughput Analysis to Represent Aircraft Utilization Rates (Topic 28). Unlike other airlift research efforts, which used planning factors for utilization rates, our research estimated these rates by modeling the operations and support of the airlift system for a specific deployment scenario. The calculations were performed for the specific routes selected for deploying the five divisions and accounted for the basic activities involved in operating and supporting transport aircraft. *This is a major departure from other airlift research for a parameter that directly affects fleet throughput.*

Utilization rates are the ratio of flying time to total elapsed time, where total elapsed time includes flying time plus ground time. Ground time includes load-related activities, servicing activities, unscheduled maintenance activities, and delays due to operational matters and weather. Ground times for load-related activities and for servicing activities were represented by factors in use at the Air Mobility Command in 1991 and 1992 (see Topic 31). These times come fairly close to the times in AFP 76-2. Another source of estimates for these ground times is the Gulf War experience.

Because AFP 76-2 does not contain maintenance planning factors, a method was devised to model ground times for maintenance as a

¹¹See Figure 4.23 in Volume 2.

function of each aircraft's maintenance history (or estimated maintenance factors for the C-17 and the 747-400F) and the length of each flight. We based ground times for delays due to operation and weather (also not contained in AFP 76-2) on the Gulf War experience.

Based on the AMC planning factors for load-related activities and servicing, the calculated utilization rates for the C-17 and the 747-400F are 12.2 and 14.7 hrs per day, respectively. Using the Gulf War ground times produces calculated utilization rates of 11.3 and 15.5 for the C-17 and the 747-400F, respectively.¹²

C-141 and C-5 utilization rates have been set at 12.5 hours per day for the first 30 days and 10 hours per day thereafter for purposes of establishing crew ratios and for airlift research. With the recent reductions in crew ratios, these numbers have come down some. The C-5's planned utilization rate is 11 hours per day. For the C-141 and the C-5, we estimated 12.2 and 7.9 hours per day, respectively, based on AMC factors; using the ground times from the Gulf War experience, we obtained slightly lower estimates of 11.7 and 7.4, respectively.

Through most of the C-17 acquisition program, the utilization rate goal has been set at 15.65 hours per day for strategic airlift. Recently, the goal has been adjusted to 15.2 for strategic airlift plus 0.45 for tactical airlift missions.¹³

Although our results show significantly lower utilization rates for both the C-5 and the C-17, the ratio for the two aircraft has remained about the same ($15.65 / 11 = 1.4$, versus $12.2 / 7.9 = 1.5$). The improved performance of the C-17 is due mostly to the improved reliability and maintenance reflected in its warranty.

The 747-400F utilization rate is higher than that the C-17, because the former spends less time on the ground because of its better reli-

¹²Of course, neither the C-17 nor the 747-400F was involved in the Gulf War airlift, so the values for these aircraft were extrapolated from the experience of similar aircraft. See Topics 30 and 31, as well as Chapter Four of Volume 2.

¹³These rates were used in the 1993 COEA for the C-17 program. With one round-trip mission cycle lasting about three days, this division of time yields an average of 1.1 hours for tactical airlift for each mission cycle.

ability and maintenance and the fact that its longer range means it has to stop less often for fuel.

DoD's COEA used utilization rates of 15.2 hrs per day for the C-17's strategic airlift role (plus 0.45 hours per day for its tactical applications) and 12.5 for the 747-400F.

Need for Consistent and Realistic Treatment of Utilization Rates for Alternative Aircraft (Topic 29). As intended, aerial refueling raised utilization rates by eliminating ground stops. Whether AMC could realistically implement the practice of changing flight crews at APOEs and APODs to achieve that intended improvement in utilization needs to be explored (see Topic 17).

To the maximum extent possible, given the fact that some aircraft have accumulated actual experience and others have not, the assessment of aircraft utilization rates in the throughput analysis was based upon a consistent consideration of the alternative transports.

Although it may seem fairer to use design goals for the utilization rates for each transport, such an approach seriously neglects reality. First, the reliability and maintenance performance of the C-5 makes the design goal unrealistic, as is demonstrated by analysis of the C-5's experience during the Gulf War airlift.¹⁴ Second, the civil-style transports have better reliability and maintenance performance than all of the military-style transports, including that which is covered by the C-17's warranty.

The lack of operational experience for the C-17 leaves our representation of the C-17's utilization vulnerable to two factors. On the one hand, if reliability and maintenance fall short of the objectives, utilization rates will be lower than we have calculated. On the other hand, if maintenance can be deferred during periods of high need,

¹⁴Our analysis of unit maintenance reports showed that the C-5B model had better reliability and fewer maintenance needs than the C-5A model that was produced about 16 years prior to the C-5Bs. Although the reliability and maintenance of the C-5B model has benefitted from design improvements, there are still significant maintenance needs that make the design utilization rate difficult to achieve. In theory, with a significant investment in the redesign and maturation of certain systems, a new model of the C-5 could come closer to achieving the design utilization rates. If the DoD decides to produce additional C-5s, it should consider a major investment in reliability and maintainability improvement.

the C-17's utilization rates would be higher than our estimates. However, we found that the C-17's utilization rate is much more sensitive to plausible assumptions about disappointing reliability and maintenance outcomes than it is to plausible assumptions about the deferral of maintenance.

Representation of the Ground Times for Loads and/or Servicing and Unscheduled Maintenance

To model comparative utilization rates, assumed ground times must reflect differences in aircraft and their ground operations. The Gulf War experience provides some insight about actual ground times during a major airlift, whereas AMC's planning factors (as of 1992) provide the Air Force's assessment of what it thought could be expected. Subsequently, the Air Staff adopted a slightly different set of planning factors that were used in DoD's COEA for the C-17.

In analyzing both Gulf War airlift experience and routine peacetime experience, we found that the largest differences among aircraft ground times were in the time needed to complete unscheduled maintenance. By explicitly modeling the time consumed by that activity, we can consistently treat each aircraft and capture one of the significant differences between types of transports that influences comparative throughput capabilities.

Gulf War Ground Times for Loads and/or Servicing (Topic 30). For the throughput and the closure time calculations, the ground times used in our analysis to account for servicing and load-related activities were based on the planning factors used by AMC at the time of this research for the C-5, the C-141, and the 747 (1992). Because comparable times for the C-17 were not available in the source document that we were provided (Ewing and Walker, 1991), we interpolated between the C-5 and C-141 times based on gross weight.

It is debatable whether the Gulf War experience is a better basis for estimating these ground times. If it is, our calculations are too generous to the military-style transports in contrast to the 747-400F.

The argument in favor of using Gulf War times is that the Gulf War airlift is the only recent data point that reflects the realities of a large-scale airlift operation. However, several arguments have been ad-

vanced for not using the Gulf War experience. One argument is that the civil-style transports were given preferential treatment throughout the airlift system, because the air carriers were only paid for missions completed and therefore lost money when their aircraft had to wait. Another argument is that they were given preferential treatment at the direction of higher headquarters. The motivation for such direction may have been contractual or possibly operational.

For example, the civil-style transports used commercial fuel (Jet A), which is a kerosene-type fuel similar to the JP-5 fuel used by the Navy. While this commercial fuel was produced in theater and was used by the Navy when JP-5 was not available, the JP-4 fuel¹⁵—then used by all of the Air Force's jet aircraft—is significantly different and had to be brought to the theater by ship.¹⁶

The civil transports also delivered more bulk cargo per unit of ramp space and per gallon of fuel consumed than did the military-style transports. Finally, after the first 30 days, from two-thirds to three-fourths of the cargo that was delivered was bulk based on monthly averages.

Ground Time Planning Factors for Loads and/or Servicing (Topic 31). Several considerations might seem to have an effect on our comparative analysis of ground times and utilization rates: (1) differences between AMC's 1992 ground-time planning factors and the Air Staff's current factors, (2) the comparative times required to load and unload pallets, and (3) the use of tugs.

- **AMC (1992) and Air Staff (1993) Planning Factors.** As just discussed, the ground times that RAND used for servicing and load-related activities were the planning factors in use at AMC at the time of this research (FY 1992) for the C-5, C-141, and 747. Ground times currently used by the Air Staff differ from the AMC's 1992 factors. Using the Air Staff's factors, however, would

¹⁵JP-4 is closer to gasoline than kerosene. Moreover, only certain refineries are prepared to produce JP-4.

¹⁶See Winnefeld (1993) and Pratt and Whitney (1974). The Air Force has subsequently explored using JP-8 in the C-141. JP-8 is similar to JP-5 and Jet A. Turbine engines will run on almost any fuel, but to achieve maximum performance, they must be adjusted to match the specific characteristics of the fuel that they will use. To achieve maximum reliability, seals may have to be changed as well.

have a small effect on the comparative results for the alternative fleets. The differences are as follows:

- AMC's loading time for the 747 was increased from 4 to 5 hours.
- AMC's en route time for the 747 was increased from 2 to 2.25 hours.
- Whereas AMC did not provide ground time factors in 1992, the Air Staff's ground times set in 1993 for the C-17 are 2.25 hours for each type of stop: loading, en route, and off-loading.

The Air Staff's planning factor for loading a 747-400F may be excessive even for loading oversize equipment, in view of loading demonstration tests conducted recently. Regarding the Air Staff's ground times for the C-17, the loading and off-loading times are better than the averages of the times for the C-141 and the C-5 (3.25 hrs for loading and 2.75 for off-loading). Perhaps that is justified by newer technology and differences in design. The en route time is also better than the average of the C-141 and C-5 times (2.75 hrs).

AMC's ground time for off loading the 747-400F (3 hrs) may be slightly high in cases in which the 747-400F does not need to refuel at the APOD. However, the effect on our calculations would be small.

Using the Air Staff's ground times in our analysis would decrease the 747-400F utilization rate from 14.7 to about 14. The C-17's utilization rate would be increased from 12.2 to about 12.8. Using such utilization rates would cause our estimate for the 747-400F throughput to decline by 5 percent and our estimate for the C-17's throughput to increase by 5 percent.

- **Pallet Loading and Unloading.** It is possible that ground times for loading and unloading pallets on military-style transports may be longer than for civil-style transports. Such a view is supported by the lack of automated powered rollers in the cargo-floor loading systems for military-style transports. Such a view is also supported by the Gulf War data. However, we do not believe that accounting for such differences would significantly affect our comparative results.

- **Use of Tugs.** We also believe that the use of tugs would have a small effect on ground time (and a modest effect on the use of ramp space).

Ground Time for Unscheduled Maintenance (Topic 32). Our approach and assumptions about ground time for maintenance were reviewed with the logistics staff at AMC at the time of the research and were recently briefed to representatives from AMC and the Air Staff. The methods, summarized in Chapters One and Four of Volume 2, provide a mechanism for accounting for the differences between aircraft and technologies. The differences in technology are taken into account by using different values for the maintenance clock hours per flying hour. When the methods were applied to the Gulf War experience, they closely replicated the observed experience of the C-5. In the instance of the C-141, however, they yielded potential utilization rates somewhat larger than the actual use of the C-141 showed. The possibility that the C-141 may have been underutilized is discussed in Chapter Four of Volume 2. The methods were applied to both the military and the civil-style transports.

The civil-style transports, as well as the C-17, were assumed to require fewer stops at CONUS bases for unscheduled maintenance than were the C-141 and C-5, because they have widely different needs for unscheduled maintenance. It is the Air Staff's current view that every transport must visit a home base for maintenance and crew changes once for each round-trip mission cycle. Such an operating policy would reduce our calculated utilization rates for all transports. The difference in utilization rates between the C-17 and the 747-400F would be narrowed by less than a few percent.

BLOCK SPEED (TOPIC 33)

Block speeds are also an important contributor to differences in throughput among alternative types of aircraft. All of the basic block speed information used in the analysis was taken from AFP 76-2 for each leg of every mission that was analyzed.

The Air Staff's position is that 409 kts (used in our analysis) is appropriate for the C-17, but the 747-400F block speed should be 450 kts instead of 462 kts. Using the Air Staff's block speeds would reduce our estimate for 747-400F throughput by 2.6 percent.

DoD's COEA used block speeds of 423 kts for the C-17 and 445 kts for the 747-400F.

THROUGHPUT CALCULATIONS

Throughput calculations were performed for two types of airlift operations.¹⁷ Most of our attention was focused on strategic airlift to support a major airlift operation, such as that required for a major regional conflict. We also calculated throughput for the brigade air drop.

Analysis Tools Used for Throughput Calculations (Topic 34)

To further the analysis community's familiarity with our analytical tools, we next consider verification of our calculations with AMC's MASS-AFM model, the manner in which performance degradations are represented, the approach to representing aerial refueling, and the consideration of the needs for specific equipment types and the need to maintain unit integrity.

Verification of Our Calculations with AMC's MASS-AFM Model. AMC and RAND have developed what appears to be an appropriate approach to using the MASS-AFM model to verify the throughput calculations for Options A, B, C, and E. To conduct this verification, AMC is using the network and the assumed values from our research. The initial results seem to verify our calculations. AMC is also exploring the sensitivity of the results to alternative networks and different assumed values for load mixes, average payloads, utilization rates, etc. We look forward to further assisting such sensitivity analyses as we complete the publication of this report.

Previous opportunities to use an earlier version of the MASS-AFM model, which was then in an earlier stage of development, were not pursued because of difficulties that were encountered regarding the representation of our scenario and the use of our inputs.

Representation of Performance Degradations. The throughput analysis treated both the military-style and the civil-style transports

¹⁷See Table 4.8 in Volume 2.

consistently regarding those matters that cause actual performance to deviate from assessments reflected in planning factors. For example, for the 747-400F, both the planning factor ground times and our representation of unscheduled maintenance time resulted in longer times than air carriers see in their operations.

Representation of Aerial Refueling. Benefits from aerial refueling can actually increase as ramp space (or fuel) in theater becomes more constrained, because aerial refueling reduces the need for in-theater refueling. However, many operational factors and scheduling challenges enter into the effective application of aerial refueling. The analysis assumes that these matters can be handled appropriately. Doing so, however, will require improvements to C⁴, as discussed previously.

Consideration of Needs for Equipment Types and Unit Integrity. As discussed previously, the analysis is based upon individual unit needs at the battalion level to move equipment, other materiel, and personnel. Results were aggregated in total tons to facilitate comparisons between fleets.

The initial missions required to open an APOD were not addressed in our analysis, because there are relatively few for the first 30-day period. It may be useful for future airlift research to take a close look at the first few days in terms of the capabilities and forces that are needed. Thus far, airlift analyses lose visibility of units and their roles once they are loaded on the ships and planes.

Analysis of Brigade Airdrop (Topic 35)

In the past, the 82nd Airborne Division has typically dropped about 125 paratroopers from the C-141, which can accommodate 150. The current configuration of the C-17 can carry a maximum of 102. A modification to the cargo floor (which would increase the structural weight, but probably only slightly so) would increase the C-17's capacity to that of the C-141. Why this contractor proposal has not been adopted is unclear. Without such a modification, the C-141 is more efficient at the brigade airdrop.

THEATER ACCESS RESEARCH

Several considerations are important to evaluating the comparative abilities of different types of transports to access a theater: (1) the technical approach to runway suitability assessments, (2) military transport features that increase access to the theater, (3) the C-17's ability to access places accessible to the C-130 and (4) the C-17's ability to use runways not usable by other intertheater transports.

APPROACH TO RUNWAY SUITABILITY ASSESSMENTS

In recent years, knowledge of runway suitability assessments has evolved to a point where the chief remaining areas of concern are AMC's concepts for sustaining airfield operations and its approach to analyzing runway suitability for different aircraft.

Evolving Knowledge of Issues in Assessing Runway Suitability (Topic 36)

In 1991, the Air Force published a paper on the C-17 that showed it could access nearly 10,000 airfields outside the U.S. in the then-free world (U.S. Air Force, 1991b). The Air Force's current assessment is that about one-third that number of airfields can be used by the C-17. The extent to which the C-17 could use those airfields as a significant APOD—say at least 5 to 10 C-17 arrivals daily for up to a couple of months—depends upon the resolution of some technical issues.

The chief issues center on the use of austere airfields, where runways are short and often not as durable as those at more established air-

fields, which have the longer and stronger runways most large aircraft require. Because data and methods in this area are limited, the issues remain unresolved. This is the first time that a large aircraft has been capable of operating on very short runways. Consequently, analyses in this area have used little empirical evidence that is directly pertinent and have had to rely on a lot of extrapolations.

AMC's Concepts for Sustaining Airfield Operations (Topic 37)

AMC seems to be relying much more heavily on the availability and capabilities of runway repair teams than is reflected in our analysis of runways suitable for major airlift operations.

While the DoD's capabilities to repair runways rapidly have been developed mainly to deal with localized damage caused by bombs, damage caused by operations of aircraft that exceed the runway's durability limits is likely to be much more extensive than bomb damage. Repair of such damage would require different equipment and materiel and would take more time than is necessary to repair bomb damage.

Moreover, such maintenance operations would detract from the purpose of the airlift operations. Thus, rather than taking the aggressive stance implicit in the AMC concept for sustaining airfield operations, we have assumed what we believe is a more appropriate and prudent perspective on APOD operations (see Topic 38).

AMC's Approach to Analyzing Runway Suitability (Topic 38)

AMC believes that the load classification group (LCG) method is the most appropriate approach for evaluating runway suitability, because it recognizes the uncertainties in evaluating runway suitability. For example, because there often are significant uncertainties about the many variables and factors that influence a technical evaluation of a runway's suitability for operations by a particular transport, it must be recognized that the resulting runway evaluation also has much uncertainty. The LCG method deals with this uncertainty by assigning runways to broad groups rather than by assigning a specific numerical value to represent the runway's suitability.

However, both the LCG method and the load classification number (LCN) method (used in our research) use LCN values that are calculated for specific aircraft.¹ Each runway suitability rating is calculated for one of two different assumptions for the expected amount of use by the aircraft of interest. The short-term rating indicates what the runway can withstand without failing over the short term (wartime assessment). The long-term rating (peacetime) indicates what the runway can withstand for ten years or more of operations.

Principal Sources of Uncertainty. Although the weight distribution characteristics of an aircraft are known with a high degree of certainty and although the distribution of stresses can be known with certainty for a given set of runway and subgrade characteristics, two principal sources of uncertainty complicate analyses of runway suitability:

- **Technical Uncertainty in Runway Ratings.** Because the Defense Mapping Agency (DMA) uses a variety of analytical methods, of varying accuracy, to assign the runway ratings, the DMA ratings have a significant amount of technical uncertainty. Often this is unavoidable, because the assessor does not have knowledge of either the soil conditions under the runway or the construction of the pavement.
- **Procedural Uncertainty in Runway Ratings.** Moreover, DMA officials report that their procedures are not applied uniformly by the worldwide force of over 100 DMA personnel who are responsible for maintaining airfield assessments (which include physical features in addition to those pertaining to runways). The procedural uncertainty is whether or not an assessor's reported rating is a short-term (wartime) rating or a long-term rating (peacetime).

Because of these technical and procedural uncertainties, it is important to exercise care in interpreting and using DMA's evaluations. It helps to start with a brief review of what the assessors are asked to do.

¹In Volume 2, see Table 5.1 and Figures 5.3 and 5.4.

Instructions to Assessors Who Rate Runways. DMA's procedures instruct assessors to report only short-term ratings. The DMA's procedures offer their assessors a way to adjust a long-term rating to a short-term rating by using LCG groups. Some DMA officials report that the procedures are widely ignored by the assessors, and most of the reported ratings are long-term (peacetime) ratings.

The procedure that assessors are supposed to follow is to take the LCN value that the runway can support over the long term and add an adjustment increment to that value to yield a short-term rating. The adjustment increment is taken from a table that defines the boundaries for each LCG. The value of the adjustment increment is simply the width of the LCG.

For example, LCG IV includes LCNs with values from 31 through 50. So, Group IV is 20 LCN units wide. The adjustment increment is simply the width of the LCG group that contains the long-term rating. So, if a runway has been assessed to have an LCN of 43 on a long term basis, its short-term rating is 63 ($43 + 20$). This means that an aircraft with an LCN of 63 may operate on the runway for about a month before the runway would no longer be usable without repairs. Alternatively, an aircraft with an LCN of 43 could use the same runway for about ten years.

Instructions to Users of Runway Ratings Who Select the LCG Assessment Method. DMA's procedures also instruct users of the DMA's ratings on how they may use LCG groups to broadly interpret the ratings.

For this purpose, the width of each LCG group is assumed to reflect the range of technical uncertainty in the DMA's reported rating. For example, assume that an aircraft has a calculated LCN value of 48. The value 48 falls in LCG Group IV, which includes LCN values 31 through 50. Group IV is 20 LCN units wide. Thus, for Group IV, DMA's position is that reported ratings within a band of 20 units may be deemed to be equivalent ratings in view of the technical uncertainty in their ratings.

There are many ways to interpret this guidance. For example:

- ***Rating Usage Interpretation 1: Runways with ratings ranging from 48 to 68 could be deemed equivalent.*** If one were selecting

an airfield to serve as a major APOD, one might want to be prudent and use this interpretation. The result would be to identify the airfields that can be counted upon as being accessible to the aircraft that has a calculated LCN of 48. This interpretation protects the airfield selection process from the technical uncertainties in the DMA's ratings that arise from inaccuracies in the rating methods.

- **Rating Usage Interpretation 2: Runways with ratings ranging from 38 to 58 could be deemed equivalent.** This interpretation implies that we are willing to risk identifying some runways (perhaps half) that will prove to be unsuitable because of technical inaccuracies in the DMA's rating methods.
- **Rating Usage Interpretation 3: Runways with ratings ranging from 28 to 48 could be deemed equivalent.** If one wanted to know the maximum number of airfields that an LCN 48 aircraft **might** be able to use, one might use this interpretation, recognizing that many airfields may prove to be unsuitable once they are more closely examined.

To ensure that it had included all of the airfields that the C-17 might be able to use, AMC used rating usage interpretation 3 and assumed that the DMA's ratings were for long-term (peacetime) use and needed to be adjusted to short-term (wartime) use. On this basis, AMC concludes that an LCN 48 aircraft could operate on runways in LCG Group V (LCN values from 16 through 30). Rather than count all airfields where each airfield's strongest runway is rated as low as LCN 16, the Air Force has used the relatively more conservative approach of requiring at least one runway at each airfield to have a rating of at least LCN 20.

We dealt with the technical and procedural uncertainties differently. We assumed that the DMA rating assigned by DMA's field personnel was determined in accordance with DMA's documented procedures² and that the rating reflected a best estimate for the expected capabilities of the runway. Thus, for an LCN 48 aircraft, we only

²We discussed this matter on several occasions with DMA's staff based in the United States. We found that the opinions of staff varied widely on whether field personnel were providing long-term use ratings or short-term use ratings. No analyses of field practices, however, could be provided.

counted those airfields that had a runway with a DMA rating of at least LCN 48.

Some contend that our approach is too conservative. However, our research team, including members of the Air Force and the Army, felt strongly that the commitment of combat forces to an APOD was a serious decision that ought not be taken lightly in either operations or analyses of investment alternatives. On the other hand, the AMC's approach is aggressive in seeking out all possible airfields that might be able to support at least a few operations.

MILITARY-STYLE TRANSPORT FEATURES THAT INCREASE ACCESS TO THE THEATER (TOPIC 39)

Features of the military-style transport in general, and the C-17 in particular, give such aircraft inherent advantages over civil-style transports in accessing places in theater.

Our research accounted for such features that generally contribute to performing the strategic airlift mission. The research considered making deliveries to small airfields, parking requirements, the ability to operate more aircraft on a ramp because of ground agility features, and flexibility in being able to carry all cargo types on outsize-capable transports. For example, the C-17's backing and ground maneuverability were considered in assessing the density with which C-17s could be parked on a ramp.

Other dimensions of flexibility, such as combat off-loads and airdrop of outsize materiel, were only considered to the extent that some significant capabilities to perform these types of missions were preserved.

Although the C-17's in-flight maneuverability advantages could be beneficial in low-level penetration of threatening environments, the opportunities to apply such capabilities may be restricted by the cost of the aircraft and the potentially limited size of the fleet. Because we have not directly included such capabilities in our analysis, the reader may want to be mindful of that exclusion when interpreting our results.

C-17's Ability to Access Places Accessible to the C-130

The extent of the C-17's ability to access places accessible to the C-130 and the utility of such access depend upon the full range of needs for intratheater airlift, the significance of any differences in the comparative access capabilities of the C-130 and the C-17, the potential roles of the C-17 in theater, and the basis for any additional needs for C-130 procurement.

Range of Needs for Intratheater Airlift (Topic 40)

Although the current inventory of C-130 transports appears sufficiently large to maintain adequate tactical airlift capabilities without needing to consider at this time procuring any new aircraft for tactical airlift, concerns about having a production capacity to satisfy future production needs prompted our consideration of the ability of the C-17 to access places accessible by the C-130.

In asking RAND to expand its research to include consideration of the production of new aircraft for tactical airlift, the Secretary of the Air Force posed the following research question: Given no current need to produce new aircraft for tactical airlift, could the Air Force close the C-130 production line and rely upon the tactical capabilities of the C-17 and the C-17 production line to fill future needs for a new tactical transport?

Because we found that the tactical capabilities of the C-17 are potentially limited and at best not yet fully demonstrated, we concluded that the Air Force should not rely on the C-17 at this time to satisfy future replacement needs for the C-130. Moreover, if our analysis is borne out by tests, the C-130 will maintain a significant tactical advantage in many areas.³

Significance of Comparative Access Capabilities of the C-130 and the C-17 (Topic 41)

We found the differences in theater access capabilities to be large and militarily significant. Even if one treated the C-17, C-5, and

³In Volume 2, see Figures 5.8, 5.9, 5.13 through 5.17, and 5.29 through 5.31.

C-130 as comparable aircraft from an LCN standpoint, in a broad-brush LCG type of analysis, there are still significant differences in their abilities to operate on roads because of their different landing strip width requirements.⁴ Moreover, there may also be significant differences in their abilities to operate on unpaved airstrips because of differences in engine vulnerability to ingestion of damaging materials.⁵ Until tests might demonstrate otherwise, the apparent tactical differences should not be assumed to be negligible.

The strongest reasons for concern lie in the different stresses aircraft apply to pavements that are indicated by both our analysis and that of the Army Corps of Engineers.

Even with significant differences, however, the C-17 is still able to make unique contributions in theater by delivering outsize cargo. Thus, it is not a matter of there being no tactical utility. The questions are: What is that capability? Is it worth enough to give up some other capability, such as some strategic airlift capacity? And, if so, how much is needed?

Role of C-17 in Theater (Topic 42)

Notwithstanding the focus of this and other research on intertheater airlift, there is a persisting question about whether or not an evaluation of the capabilities and the costs of alternative airlift fleets for strategic airlift should consider tactical airlift functions.

The following are the main points supporting inclusion of tactical airlift functions: (1) The C-17 should be applied to some of the theater tactical airlift missions; (2) C-130s need to complete the delivery of materiel brought to the theater by any 747-400Fs that might be procured in place of the C-17; and (3) only a small percentage of the C-17's time needs to be diverted from its strategic airlift role.

The C-17 Should Be Applied to Some of the Theater Tactical Airlift Missions. The argument that the C-17 should be applied to some tactical airlift missions because of its capabilities in that area ignores

⁴The C-130 used roads as landing strips during the Gulf War.

⁵See Chapter 5 in Volume 2.

the reality that there is an ample supply of tactical airlift, while strategic airlift is threatened with rapid decline as the C-141 fleet retires. Each hour a C-17 provides tactical airlift would add to any shortfall in strategic airlift.

C-130s Need to Complete the Delivery of Materiel Brought to the Theater by Any 747-400Fs That Might Be Procured in Place of the C-17. Many other research efforts that have compared alternative airlift fleets have included the costs to procure, operate, and support a C-130 fleet in each fleet mix option that did not include a full procurement of the C-17. The reasoning has been that such inclusion of C-130s was necessary to level the playing field by making each fleet mix more nearly balanced between strategic and tactical airlift.

However, that C-130s must be bought to level the playing field presumes a major shift in operational concepts that may or may not occur. Even if 120 C-17s were procured, only 33 percent of the transports arriving daily in theater would be C-17s in our scenario. CRAF would account for 20 percent of the daily arrivals. Once in theater, each unit assembles its personnel and materiel prior to commitment to theater operations. During the period of assembly and preparation, as the unit's final deployment loads are being delivered, there is time to move personnel and materiel within the theater by various means, including surface and air transportation. Most such movement, however, occurs by surface.

Moreover, for situations where C-17s would land at the same major airfields as the 747-400F and other transports, there is no need for the assumed movement. For the Gulf War airlift, over 40 APODs were used without the presence of a C-17. Although the C-17's capability to access austere fields might be used on occasion during the deployment phase, it is more likely to be used during the sustainment phase.

A Small Portion of the C-17's Time Is Needed for Tactical Missions. While engaged in a strategic airlift mission cycle taking up to two days to complete, a C-17 cannot also be conducting tactical missions in theater. At the time of our research, AMC's concept of shared operations was that, upon landing at an in-theater airfield, the C-17 would refuel and carry the load on board to its final destination. The alternative concept is to pick up a tactical load at the APOD and de-

liver it to a tactical location in theater before resuming the strategic airlift role.⁶ The total flying time on the tactical mission might be only 1.1 hours. Compared to the 36 or so hours spent flying its strategic airlift mission cycle, 1.1 hours would only represent about 3 percent of the average daily utilization of the aircraft.

Such a concept of shared operations would seem to face several challenges. How does the concept of performing tactical airlift missions at the convenience of the schedule of a strategic airlift transport fit with theater needs? Would execution of the concept generate additional ground time that would lower the C-17's utilization rate? In other words, how much more time is involved besides the 1.1-hour flight time? Would two refuelings instead of one be required in the theater if the austere airfield lacked refueling capabilities? What happens if the tactical mission requires daylight (or night) operations and the C-17 arrives late and it is already dark (or daylight)?⁷ If the C-17 needs to contribute to tactical operations, such as outsize air drop or tactical deliveries of outsize to austere airfields, it would seem far more likely that some number of aircraft would be assigned to those operations, and their crews would be trained accordingly. In any event, at the time of the research in 1992, it was far from obvious that a plan for shared operations had yet matured to a point where serious analysis of alternatives could proceed.

Basis for Additional C-130 Procurement (Topic 43)

In researching the question of whether the Air Force could close the C-130 production line and rely on the C-17 for future tactical airlift needs, we found that there is an opportunity to modernize the C-130 design in ways that would reduce its operation and support costs and potentially increase its performance and access to theater airfields. Whether a production capability should be maintained is problematic, because the next significant retirement of C-130s is not scheduled until 2007, with about one-fourth of the fleet of 410 aircraft retiring. If the DoD decides to maintain a production capability, it seems

⁶Another concept is for the C-17 to take its load directly to its final destination. That may not have been AMC's planned concept of operations at the time of our research, because few austere airfields are likely to have JP-4 fuel available to refuel the C-17.

⁷The C-17 is capable of night operations at austere airfields.

worth considering the costs and benefits of converting the production to the C-130J configuration. Such conversion seems to be happening anyway to satisfy demands from other countries.

THE C-17'S ABILITY TO USE RUNWAYS NOT USABLE BY OTHER INTERTHEATER TRANSPORTS

Next, we examine the C-17's advantage over the 747-400F and the C-5 in accessing airfields.

The C-17's Ability to Use Runways Not Usable by Civil-Style Transports (Topic 44)

Our research demonstrated that the C-17 can access significantly more airfields than the 747-400F based upon considerations of runway strength and length. We also explored whether this difference might be even greater when considerations are expanded to include the width and strength of taxiways and the size and strength of ramps.⁸ The further considerations did not significantly widen the C-17's advantage, because airfields with runways that are long and strong enough for the 747-400F also tend to have adequate taxiways and ramps.

The C-17's Comparative Ability to Support Major APOD Operations (Topic 45)

We examined the abilities of alternative transports to use airfields to support major APOD operations and considered (1) C-17 access relative to 747-400F access, (2) C-17 access relative to C-5 access, and (3) the use of austere airfields for major APOD operations:

- **C-17 Access Relative to 747-400F Access.** Our analysis agrees with the Air Force's assessment that the C-17 can access significantly more airfields than can the 747-400F. Air Force results show a difference of a factor of five, whereas RAND's results

⁸Other characteristics that we did not analyze that affect the ability to use an airfield include local terrain and clearances around runways, taxi ways, and ramps.

show a factor of three.⁹ The difference is attributable to the difference in methods (LCG versus LCN) discussed previously under Topic 38. Use of a somewhat shorter runway in RAND's analysis (8,000 ft instead of 9,300 ft) for the 747-400F has little affect in the comparative results.¹⁰

- **C-17 Access Relative to C-5 Access.** Here there is significant disagreement between our results and the Air Force's results (see Topic 38). By using a broad-brush approach and aggressive assumptions to avoid missing airfields that might be usable by the C-17, the Air Force ends up with an approach that fails to discern any differences between the C-5 and the C-17 in their runway thickness and strength requirements. Our approach found that the C-17 creates significantly higher stresses on runway pavements than either the C-5 or the C-130.¹¹ The Army Corps of Engineers has found similar differences.¹² Our results show that the C-5 and the C-17 have similar capabilities to access airfields for major APOD operations, given criteria that seem appropriate to the designation of an airfield as a major APOD.
- **Use of Austere Airfields for Major APOD Operations.** Austere airfields are not particularly well-suited for major APOD operations, because deploying forces are moved by a mix of inter-theater transports, including civil-style transports operated by civil air carriers. For major relief operations, the Air Force has the option of using the C-130 without incurring nearly as much risk of damaging a runway.

⁹See Figure 5.18 in Volume 2.

¹⁰Our assumptions on landing conditions (rain, temperature, and altitude) may have been different from those used by other analysts who have used 8,000 ft for the runway length suitable for 747-400F landings.

¹¹See Figure 5.14 in Volume 2, where the LCN parameter provides an indication of stress levels.

¹²See Figure 5.13 in Volume 2, where the ACN parameter provides another indication of stress levels.

The C-17's Comparative Ability to Support Limited Operations During Wartime (Topic 46)

RAND and the Air Force have taken fundamentally different approaches to the analysis of the suitability of LCN 20 runways and we have arrived at very different results. Given the lack of experience, including empirical evidence, for using heavy aircraft on low-strength runways, and given the primitive state of analytical methods in this area, it is not surprising that different research approaches are producing widely divergent results.

For example, consider the Air Force's assessment that a C-17 as heavy as 425,000 lbs could operate on runways DMA has rated as low as LCN 16 for 30 to 45 days with a limited number of passes and no damage to the runway. Using a different method of analysis described in the literature (see Volume 2, Chapter Five) we found that a C-17 at a lower weight would fail a new asphalt runway with an LCN 20 rating in 30 to 55 landings, depending upon the strength of the subgrade.¹³ That result was based on the assumption that the LCN 20 rating was a long-term rating. When we changed that assumption to a short-term rating, our calculations predicted that the runway would fail after about eight landings.¹⁴

Similarly, for a concrete runway with an LCN 20 rating, we found that the first landing would cause widespread cracking.¹⁵ This result was produced by using a methodology that is an accepted industry standard (see Volume 2, Chapter Five). The Air Force has used a different method that projects that 100 landings could be supported.

¹³See Figure 5.23 in Volume 2.

¹⁴See Figure 5.22 in Volume 2.

¹⁵See Figure 5.21 in Volume 2.

COST RESEARCH

The cost research had several dimensions that have a significant bearing upon the results: scope of the cost analysis, determination of fleet sizes, approach to estimating acquisition costs, approach to estimating operation and support costs, data sources, operational suitability of the least-cost fleet mix option for the future, and the overall breadth and depth of the analysis.

SCOPE OF THE COST ANALYSIS

Tables D.1 and D.2 summarize the main results of the cost analysis for Options A through E. To illustrate the rationale for the scope of the cost analysis, we will examine the reasons for the inclusion or exclusion of the cost of aerial refueling, materiel handling equipment, and in-theater transportation.

Inclusion of Aerial Refueling Costs (Topic 47)

Our analysis included the operation and support costs of the tankers that were dedicated to refueling the C-5s in Option D, because those tankers would need to be dedicated exclusively to supporting the C-5s during training and contingency operations. Because AMC is already using tankers to support airlift operations, we did not include the cost of procuring tankers but used only existing tankers.

Table D.1
Fiscal Costs for the Options

		25-Year Total Cost: 1993–2017 (millions of 1992 dollars)		
		1992 Present Value		
Analysis Case			5% Discount	10% Discount
Label	Description	Cost	Rate	Rate
Base case	Keep 126 C-5	25,900	14,200	8,700
	Keep 94 C-141	22,100 ^a	11,600	8,000
	Total for base case	48,000	25,800	16,700
Option A	Buy 120 PAA C-17	38,800	26,200	19,200
	Total increase	38,800	26,200	19,200
Option B	Buy 60 C-17	20,500	14,000	10,300
	Buy 60 C-5C	22,700	14,800	10,200
	Total increase	43,200	28,800	20,500
Option C	Buy 60 C-17	20,500	14,000	10,200
	Buy 28 747-400F	9,700	6,100	4,200
	Total increase	30,200	20,100	14,400
Option D	Buy 28 747-400F	9,700	6,100	4,200
	Use 59 KC-10, and	5,800	3,200	1,900
	Add 2.4 crews per C-5	20,700	11,400	6,900
	Total increase	36,200	20,700	13,000
Option E	Buy 42 747-200	14,600	9,200	6,300
	Total increase	14,600	9,200	6,300

^aIncludes an allowance of \$3.5 billion for service life extension.

Exclusion of MHE Costs (Topic 48)

We examined the costs of MHE equipment and the potential differences in MHE costs for the options of interest in Volume 2. When we found that differences in MHE costs for the options would not be

Table D.2
Infrastructure Costs for the Options

Analysis Case		Ramp Space in Theater (thousand sq ft)	Fuel Consumption (tons)	Transport Arrivals		Crew Member Arrivals
Label	Description			Civil Style	Total	
Base case						
	Keep 126 C-5	967	7,760	0.0	18.4	110
	Keep 94 C-141	353	4,745	0.0	20.0	100
	Keep 28 CRAF 747 cargo	395	3,611	9.7	9.7	39
	Keep 18 CRAF 747 passenger	253	2,321	6.2	6.2	25
	Total for base case	1,968	18,437	15.9	54.3	274
Option A						
	Buy 120 PAA C-17	370	7,119	0.0	25.6	77
	Total increase	370	7,119	0.0	25.6	77
Option B						
	Buy 60 C-17	185	3,560	0.0	12.8	39
	Buy 60 C-5C	452	3,631	0.0	8.6	51
	Total increase	637	7,191	0.0	21.4	90
Option C						
	Buy 60 C-17	185	3,560	0.0	12.8	39
	Buy 28 747-400F (24 PAA)	336	2,825	8.5	8.5	25
	Total increase	521	6,385	8.5	21.3	64
Option D						
	Buy 28 747-400F	336	2,825	8.5	8.5	25
	Use 59 KC-10, and		2,763	0.0		
	Add 2.4 crews per C-5	289 ^a	1,477	0.0	5.5 ^b	106
	Total increase	625	7,065	8.5	14.0	131
Option E						
	Buy 42 747-200	506	4,238	12.8	12.8	38
	Total increase	506	4,238	12.8	12.8	38

^aC-5 with aerial refueling less C-5 without refueling = 1256 - 967 = 289.

^b23.9 - 18.4 = 5.5.

large enough to have a significant effect, we elected to exclude them from further consideration. The cost differences would have been small for two reasons. First, MHE costs much less than aircraft to ac-

quire, operate, and support. Second, all types of transports require MHE for efficient loading and unloading of pallets.

Exclusion of Costs for in-Theater Transportation (Topic 49)

Our analysis of alternative fleets did not include the life-cycle cost of a C-130 fleet for those options that did not include a full procurement for the C-17. As discussed under Topic 1, our analysis focused on satisfying needs for strategic airlift and (as discussed under Topic 42), notwithstanding the C-17's tactical capabilities, the greatest need is to replace the strategic airlift capacity that will be lost in the retirement of the C-141. Moreover, at least in the near term, tactical airlift capabilities appear to be sufficient.

DETERMINATION OF FLEET SIZES (TOPIC 50)

Because fleet size has a direct effect on costs, we will now review a couple of matters regarding the assessed sizes of the 747-400F fleet and the C-5 fleet.

747-400F Fleets for Options C, D, and E

The size of the 747-400F fleet may be overstated by as much as 10 percent, because we used the same assumption for calculating backup aircraft for both the military-style and civil-style transports.¹ It can be argued that fewer backup aircraft are required, because the civil-style transports have greater reliability and less need for being withdrawn from service for major maintenance.

C-5 Fleet for Option B (Additional Procurement)

We believe that the assessment of the size of the additional procurement of C-5s for Option B is sound, because it is based upon utilization rates and payloads that resulted from what we believe are reasonable and equitable representations of the airlift system, its aircraft, and their operations and support.

¹The number of backup aircraft equals TAI less PAA, where TAI is total aircraft inventory procured and PAA is the primary aircraft assigned.

On the other hand, notwithstanding our efforts to level the playing field, some argue that the C-5 was handicapped in our analysis compared to the new aircraft (the C-17 and a DoD-operated 747-400F), because we used factors derived from actual operational experience for the C-5 and used only estimates for the new aircraft. The concern about the estimates is that they may not fully reflect degradations that often occur when new systems are actually operated and supported by the DoD. Inadequate procurement of spare parts is of special concern in this area.

Although historical evidence supports this proposition, it is not likely to affect the major results of the research. Unless there is a very negative outcome for the reliability, maintainability, and support for the C-17, our sensitivity analysis shows that this issue alone is not sufficient to make a big difference in the results for Option B compared to the other options.

APPROACH TO ESTIMATING ACQUISITION COSTS (TOPIC 51)

Because the scope of modifications to the 747-400F configuration remains to be defined, it is useful to clarify how we treated its costs. First, we independently estimated that it would cost the DoD about \$150 million (1992 dollars) to purchase a 747-400F, based upon recent commercial experience. We then added an allocation of \$20 million to cover reasonable modifications. On the other hand, if the DoD were to procure a significant quantity of 747-400Fs in a standard commercial configuration, it could negotiate a better price, perhaps 10 to 15 percent lower than what we allocated in the cost analysis. However, after operation and support costs are included, the percentage effect on the total life-cycle cost would be less pronounced and certainly small compared to the cost differences among the options.

APPROACH TO ESTIMATING OPERATION AND SUPPORT COSTS (TOPIC 52)

Because operation and support costs are strongly influenced by the annual flying-hour requirement to train and maintain aircrews, we

will now review how we handled aircrew flying-hour needs generally, and particularly for the C-17.

The number of flight crews required per primary aircraft assigned (PAA) for each aircraft was calculated by examining past average experience (about 90 hours per month per flight crew)² and assuming a continuing high tempo of operations over a six-month period. The individual limits expressed in AFR 60-1 were not used, because they do not reflect the normal flow of pilots through the training and upgrade process and do not reflect the overhead positions required to sustain that process.

The C-17 flying-hour program AMC supplied for our research provided for 286 hours annually per flight crew. The C-141 flying-hour program provided for 287 hours annually. Thus, for the purpose of our analysis, no additional flying for tactical missions appeared to be factored into the C-17's operation and support costs.

On the other hand, one might question the need for a fifth flight crew per PAA (called for by Air Force plans in 1992), given our estimates for the utilization rates. Both the C-17 and the 747-400F were assumed to have five flight crews per PAA.³

If the C-17 crew ratio were reduced to four, and if the annual flying-hour program for the fleet held constant, about 70 hours would be available annually for tactical training. One could argue that the cost of that tactical training should not be charged to the C-17 in this analysis, because no C-17s were assigned to tactical airlift missions. This identifies a fundamental dilemma with the C-17 concept of performing both tactical and strategic airlift. Given that the shortfall in airlift capacity is in the strategic rather than the tactical mission area, why should DoD expend scarce resources training flight crews to fly tactical missions? In all likelihood, they will not be available to

²Historically, in the airlift mission area, the Air Force has maintained four flight crews per PAA to support the capability to fly 12.5 hours per day for a 30-day period and 10 hours per day thereafter.

³Using its planning factor utilization rate of 15.65 hours per day at the time of the research in 1992, the Air Force was planning on five crews per C-17. We made a comparable assumption for the 747 to support the high utilization rates that we were estimating for its operation.

conduct such missions, because the aircraft will be satisfying higher-priority needs in the strategic airlift mission area.

The counterargument is that the C-17 can deliver directly to austere airfields. The issue, though, is how often that will be necessary during a large airlift, in which many large airfields must be used in the theater, including ones that can accommodate the CRAF and any civil-style transport that the DoD might operate.⁴

COST DATA SOURCES (TOPIC 53)

The basic sources for the cost data for the military-style transports were the usual government sources, including the most recent System Acquisition Reports for the C-17 and the C-5B, and the Air Force's SABLE⁵ model and database for operating and support costs. For the 747-400F, we used commercial procurement experience cited in the literature. Modification costs for the 747-400F were based upon the experience of the commercial sector and of the government.

In instances where cost information was not directly available from a standard source, the cost breakdown for the most comparable aircraft was adjusted to estimate the costs for the transport of interest. Analyses based upon comparable aircraft were used to estimate acquisition costs for a further procurement of the C-5 (using C-5B experience) and operating and support costs for the C-17 (using the C-141) and the 747-400F (using the KC-10).

Cost estimates for extending the life of the C-141 were obtained from the prime contractor.

⁴Another consideration is, how often would a valuable resource be sent to an exposed forward field? Generally, the less costly and more numerous C-130s have spared the C-5s from such exposure.

⁵Systematic Approach to Better Long-Range Estimating (SABLE) is a cost database and model maintained by the Air Staff.

IS THE LEAST-COST FLEET RESPONSIVE TO WAR-FIGHTING NEEDS? (TOPIC 54)

After finding the least-cost fleet mix, it is reasonable to inquire whether such a mix would adequately satisfy DoD's broad range of needs for air mobility.

The least-cost fleet (Option E) has the best prospects for meeting future needs for airlift, because it is most likely to be fully procured. Given current fiscal realities, full procurement of the Option A fleet is not nearly as likely as a full procurement of the Option E fleet (or one closely resembling it).

To avoid the situation in which closure times would become unacceptably long, it is important for the DoD to select an option that it can afford to fund fully. The fleet, however, must also have a mix of capabilities sufficient to ensure that the mix of needed equipment and supplies can be deployed during the early days of an airlift. The option the DoD selects, therefore, must be a solution that is both affordable and sufficient to satisfy national needs.

Because flexibility in cargo delivery—the ability of an aircraft to handle any mix of materiel—and flexibility in delivery options come at a premium price, flexibility and capacity are in competition for the defense dollar. Too much investment in one will hurt the other. To deploy the forces needed during the early days rapidly, the airlift fleet needs the right balance between capacity and flexibility. The goal of our research has been to help inform decisionmakers how that balance might be achieved.

From our results, it appears that sacrificing some flexibility in the interest of capacity is a necessary trade at this time. Adoption of this trade, however, means that the military airlift inventory would include transports that lack the C-141's flexibility to go places that cannot receive a 747-400F.

Whatever the course that the DoD pursues, it is important for it to verify that the option it finally selects is one that can deliver the right mix of materiel and personnel to the right places during each critical phase of a major airlift operation. Although each of the five options we examined seems to have the capacity to do these things in a satis-

factory manner, there are differences among the options that the DoD will want to weigh carefully.

ADEQUACY OF THE ANALYSIS FOR THE LEAST-COST FLEET (TOPIC 55)

In thinking about alternatives for the right mix and assessing the merits and costs of alternatives, it is reasonable to inquire about the adequacy of the analysis that underlies the findings from this research.

On the one hand, we believe that, relative to the standards for completeness, depth, and quality of workmanship reflected in other research efforts, our research provides an adequate basis for the findings and conclusions presented in the report.

On the other hand, we would be the first to acknowledge that further investment in research could explore more possibilities and sharpen the estimates of both costs and benefits. Moreover, selected experiments could provide data that may narrow some of the uncertainties that have been discussed.

Meanwhile, however, there is an urgent need to make major decisions about airlift investments. Although we believe our analysis and its results are useful contributions to such decisions, we encourage the DoD to pursue further research in this area.

DIFFERENCES IN RESEARCH METHODS EXPLAIN WHY RESEARCH RESULTS ARE SO DIFFERENT

Our results differ from those of others, because we used research methods that examine some important distinctions among alternative fleet mixes in different detail. This appendix illustrates the differences in the research methods of several recent analyses. The knowledge that has been produced by all of these research efforts will contribute to informing future choices only if the key differences in the analysis methods and the implications of those differences are explained.

USTRANSCOM (AMC) ANALYSES (TOPIC 56)

The differences in perspectives and results between our research and that of USTRANSCOM seem to stem largely from differences in three areas:

- **Satisfying the CINCs' needs.** The warfighting CINCs need both capacity and flexibility in airlift capabilities to meet their needs for rapid movement of resources that are not prepositioned or moved by ship. Without fiscal limitations, the CINCs can have both needs satisfied. As fiscal limits become tighter, however, either flexibility or capacity (or both) must be sacrificed.
- **Infrastructure considerations.** USTRANSCOM believes that it has used infrastructure assumptions equivalent to what was experienced during the Gulf War airlift. It appears, however, that the infrastructure constraints used in the USTRANSCOM analyses and the C-17 COEA (see Topic 60) may have been tighter than what was experienced during the Gulf War.

Regarding our analysis, the five options that we examined result in the arrival of from 67 to 80 transports in theater daily. During the first 30 days of the Gulf War airlift, an average of 62.5 transports arrived daily. During the peak month of the airlift, an average of 100 transports arrived daily. Each of the options in our analysis requires no more theater infrastructure than was actually used during the Gulf War, with the exception of a need for a modest amount of additional MHE for Options C and E.¹

- **Ramp space assumptions.** We agree with USTRANSCOM that, given the assumptions that other research has made about payloads and parking requirements, the less ramp space one assumes to be available, the better the results for a C-17 fleet compared to any of the other alternatives considered.

However, for the movement of bulk cargo, and with a different assessment of the payload, we find that the C-17 and the 747-400F deliver about the same amount of cargo per unit of ramp space. With what might be more realistic assumptions about parking requirements, the 747-400F does a little better than the C-17. When delivering oversize cargo, the C-17 maintains an advantage over the 747-400F because of the 747-400F's lower payloads for that class of cargo. The C-17's advantage derives from our assumption that C-17s can be densely parked on a ramp as a consequence of their superior backing and maneuverability capabilities. If such a dense parking arrangement proves impractical because of the need for ground equipment to have space to operate and unload aircraft while other aircraft enter and exit the ramp area, the C-17 and the 747-400F would have more nearly comparable throughput capability when carrying oversize materiel.

ANALYSES BY THE AIR MOBILITY COMMAND (TOPIC 57)

Although our research had a perspective and an approach that is different from the traditional approach the Plans and Analysis staff at AMC used, we have found the intellectual exchanges with the AMC

¹As noted under Topic 48, we did not estimate the amounts of MHE required for each option.

staff to be very productive and helpful to the development of our research and this report. Because any approach has its strengths and weaknesses, we found the existence of an alternative approach to be helpful in many ways, not the least of which being that it improved our appreciation of the many matters that influence the performance of the airlift system.

One of the areas of mutual interest has been aerial refueling. For over a year, the difference in results for the estimated benefit of aerial refueling was 6 percent (AMC) versus 30 percent (our report). For about a year, the cause was thought to lie with a policy difference about where crew changes would occur and a modeling difference about whether air base infrastructure should be represented by explicit constraints or analyzed with a method of resource impact assessment. Then AMC recognized that their 6-percent result had been driven by a different kind of constraint altogether. The total air crew constraint had been the limiting constraint, because the total number of air crews that were assumed qualified for aerial refueling reflected conditions as they existed at the time of AMC's calculations. Because this constraint can be relaxed by training more crews, the difference between AMC and our research is less than it at first appeared.

Although there are still other differences, such as whether crew changes can occur at the APOEs and APODs, that would cause any new AMC calculations to differ from our results, the important point is the time it took to recognize what was driving part of the difference in results. This illustrates difficulties in using models that are based on the method of explicit constraints. Understanding which constraint is driving the results over the time period analyzed can be a real challenge under even the best of conditions. Indeed, the constraint that limits airlift system performance can change as a function of time as different resources (such as refueling capacity) are used up until another resource (such as air crews) is used. Such behavior is particularly worrisome when the constraint can be relaxed by reallocating resources at far less cost than the cost difference between fleet options. For example, training additional air crews and procuring additional trucks for refueling could be far less costly than attempting to buy a faster transport that consumes less fuel.

DOD'S COEA FOR THE C-17 PROGRAM

The COEA, requested by the Congress and performed during 1993 by IDA with the assistance of OSD/PA&E and the Air Force, was a short-term special-assistance effort that produced an independent analysis of costs and operational effectiveness of the C-17 and alternative airlift programs, including mixes of aircraft types.

The COEA mostly considered the two-major regional conflict (MRC) scenario from the Defense Planning Guidance. A lesser regional contingency was also examined but did not play a significant role in discriminating between alternative fleets. The scenarios were provided by the DoD.

Differences in Research Efforts (Topic 58)

The COEA and the research described in our report were conducted under different circumstances and for different purposes. Even so, there are many similarities between the two efforts. Both efforts focused mainly on strategic airlift for a major regional need(s). The main focus of both efforts was comparing alternative fleets on the basis of cost and performance. The methods used for both the cost analyses and the throughput analyses have common roots. Many of the sources for basic cost and airlift factors were the same.

That is not to say that the approximations, the depth of the research, and the sophistication of the analysis methods did not differ in ways that reflect the research settings and the research objectives. That was certainly the case. The efforts also differed in their charge. Our guidance was to draw upon the experience of the Gulf War airlift, as well as changing world conditions and other relevant factors. This gave our research some significant roots in the Gulf War experience that may or may not prove relevant to the future trends in airlift needs and operations. The COEA, on the other hand, presents an analysis with a different perspective on the right mix. For example:

- The large amounts of bulk cargo that were delivered by airlift during the Gulf War are not reflected in the loads that DoD provided to IDA for the COEA analysis.

- Also, as is discussed below, our research finds that the COEA overestimated the cargo density, utilization rates, and block speeds for the C-17 and underestimated the same factors for the civil-style transport.

This contrast highlights the sensitivity of calculations to the research methods used to analyze key parameters. Future research and subsequent decisions can benefit from these findings by understanding how such differences have led to such different results. Below, we examine the main differences in methods and their implications, but first we need to describe the COEA's analysis cases.

COEA's Analysis Cases (Topic 59)

The COEA analysis focused on 26 alternative fleet mixes. Each mix was examined for varying assumptions on the capacity of airfields to handle transport aircraft on the ground simultaneously. Under the *Robust* infrastructure case, the airlift system seems to have performed with no degradations due to infrastructure limitations. The *Moderate* and the *Constrained* infrastructure cases introduced progressively more severe constraints. In addition to these three MOG cases, many sensitivity cases were evaluated to examine alternative assumptions in such areas as (1) the 747-400F's ability to carry over-size trucks; (2) utilization rates for the C-17, C-5 (new procurement), and 747-400F; (3) alternative cost analysis results; (4) alternate phasing of procurement; and (5) further variations in the composition of the fleet mixes requested by DoD.

COEA's Method for Analyzing Use of Ramp Space (Topic 60)

Influence of Ramp Space Constraints on the COEA's Results. When the Moderate and Constrained MOG cases were used for evaluating alternative fleets, parking constraints and differences in the amount of parking space required by different transports began to have a significant influence on the results. The COEA describes the Moderate MOG case as based upon an AMC analysis of the capacity of the infrastructure that supported the Gulf War airlift, especially during the first 30 days.

Use of Ramp Space During the Gulf War Airlift. Our analysis of the Gulf War airlift, however, suggests that infrastructure considerations go far beyond the matter of parking spaces and are probably best dealt with on their own terms rather than in the form of an aggregate constraint that is used mainly to manage parking. For example, the number of transports actually parked at any given time in theater was rather modest relative to the number of airfields involved. Moreover, in the Gulf War, when the theater's ability to receive more transports daily had to be increased, it was increased:

- **67 Daily Arrivals During the First Several Weeks.** An average of 67 transports entered the theater daily during the first several weeks of the Gulf War airlift. From reported ground times and arrival rates by airfield, it appears that the average number of transports parked at all airfields in theater was 7.8 during the first 30 days. An average of 4.6 transports was parked at Dhahran. The remaining 3.2 were parked as follows. On average, a total of two was parked at Riyadh, Jubail, King Fahd International Airport, and Bahrain International Airport, and on average a total of 1.2 was parked at the remaining airfields, including Thumrait, Shaikh Isa, Taif, Al Dhafra, and King Abdul Aziz.
- **96 Daily Arrivals During the Sixth Month.** An average of 96 transports entered the theater daily during the sixth (and busiest) month of the Gulf War airlift. Although the average number of aircraft parked daily at Dhahran appears to have remained at about 4.6, the next busiest set of four airfields saw the average number parked triple from the two during the first 30 days to six (for all bases) during the sixth month. These four airfields (Riyadh, Jubail, King Fahd International Airport and Bahrain International Airport) bore the brunt of the increased arrivals. There were an average of 28 more arrivals daily than during the first several weeks of the airlift. For all airfields, during the sixth month, an average of 12.4 transports was parked in theater.

In terms of C-5 equivalent parking spaces, the first month had an average of 5.1 spaces in use, while the sixth month had an average of eight spaces in use. The COEA's Moderate MOG case limits the number of C-5 equivalent aircraft in theater simultaneously to five.

Use of MOG Constraints in Models. If a MOG of five was used in the ACAS model (a steady-state model), the COEA would appear to have represented an infrastructure condition that existed during the first several weeks.

Using a MOG of five in the MASS-AFM model, however, could constrain the airlift system to levels of performance below those achieved during the Gulf War, because MASS-AFM is a dynamic simulation that follows the movement and bunching of aircraft in the airlift system. Using five as a hard constraint would mean that no more than five would ever be allowed, although fewer than five would. Consequently, the average number parked would end up being less than five, and the system's performance would be less than that observed during the Gulf War airlift.

But Is Five Parking Spaces the Right Issue? What changed at Riyadh, Jubail, King Fahd International Airport, and Bahrain International Airport that allowed daily arrivals to increase from 18 during the first several weeks to 46 during the sixth month?

One change was that it became clear that additional arrivals would have to be accepted at theater airfields to satisfy the theater's needs for additional materiel. To help satisfy those needs, the participation of civil transports was increased (including the January 17 activation of CRAF Stage II). About one-third of the increased daily arrivals was provided by the increased support of civil transports. Other differences from the first several weeks were the activation of more flight crews and the refinement of scheduling and loading at APOEs. This is not to deny the importance of improvements in infrastructure within the theater. But these other factors seem to portray a far more complex situation than can be represented by addressing only the allocation of parking spaces.

Finally, there is dispute about just what the binding constraint on throughput was. The Air Staff's current view is that it was providing fuel rather than ramp space.

COEA Loading and Throughput Analysis Methods (Topic 61)

The COEA used methods to assess the throughput capabilities (Table E.1) of alternative fleets that were drawn from the Air Force's stable of airlift research tools.

- **The Airlift Loading Model (ALM).** To determine what cargo and how much will fit onto which aircraft, the COEA used the ALM, currently in use by the Air Force Studies Agency. The time-phased load delivery dates and the load characteristics for the two-MRC scenario were provided by OSD/PA&E.
- **MASS-AFM.** Under the guidance and assistance of IDA's COEA study team, the AMC used its MASS-AFM model to simulate aircraft and cargo flows for the two-MRC scenario. The simulation assigned routes within MASS-AFM, used payloads within the limits determined by ALM, and delivered payloads to the prescribed destinations.
- **ACAS.** The COEA study team used AMC's Airlift Cycle Analysis Spreadsheet (ACAS) model to examine sensitivities of the results to selected assumptions.

IDA reports that the COEA research used a loading algorithm that is less efficient for outsize but believes that it is operationally realistic and conforms to current AMC loading procedures. Although this algorithm may be consistent with AMC's procedures for modeling the loading of outsize-capable transports, our research suggests that it is inconsistent with the way the Army (the service with the most outsize materiel) prepares many—and perhaps even most—of its loads for that class of transport (see Topic 18).

COEA Cost Analysis Methods (Topic 62)

Independent cost analyses were performed for each alternative fleet, and the sensitivity of results to Air Force cost estimates was explored. The methods and sources of the COEA were similar to those we used. However, the COEA used more recent information to estimate the costs for the C-17 and the 747-400F. Generally, our results for procurement costs are similar. However, the COEA has higher estimates for operation and support costs for the C-17 and lower costs for the

Table E.1

Influence of C-17 COEA Assumptions for Payload, Utilization, and Speed on Differences in Estimated Throughput^a

RANDMR406/3-1E.1

Single Aircraft	Average payload (lbs)	X	Utilization rate (hrs/day)	X	Block speed (kts)	X	Route productivity factor	/	One-way distance (n mi)	=	Daily deliveries (lbs)
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747-400F

RAND

Bulk 223,200 14.7 462 0.47 7,000 101,778

Oversize^a 145,000 14.7 462 0.47 7,000 66,119

COEA 146,200 12.5 445 0.47 7,000 54,603

C-17

RAND 74,800 12.2 409 0.47 7,000 25,060

COEA 96,600 15.2 423 0.47 7,000 41,702

Fleet	Single aircraft delivery (lbs)	X	Total aircraft inventory	X	PAA per TAI	X	Percent of PAA used/ 100	/	2000 lbs per ton	=	Daily deliveries (tons)
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747-400F

RAND

Bulk 101,778 42 0.85 0.75 2,000 1,363

Oversize^b 66,119 42 0.85 0.75 2,000 885

COEA 54,603 42 0.85 0.75 2,000 731

C-17

RAND 25,060 120 0.85 0.75 2,000 959

COEA 41,702 120 0.85 0.75 2,000 1,595

^aAverage daily deliveries for single aircraft and fleets.^bOne-third of cargo is bulk.

747-400F. At the time of our research, the Air Force could not provide information for many of the factors that influence operation and support costs.

Interpretations of the COEA's Results (Topic 63)

Whereas some readers of the COEA report (Greer, 1993) find the procurement of 120 C-17s the most cost-effective option, even with a robust infrastructure, others may see a mixed buy of C-17s and 747s as a better approach after they explore the sensitivity of the results to such matters as utilization rates. Our research found that buying only 747-400Fs was the least-cost option. The following seem to be the main reasons for this difference (see Table E.1 for key parameter values):

- Different methods for estimating payload for the C-17 versus the 747-400F.
- Different methods for estimating utilization rates for the C-17 versus the 747-400F.

The following are other significant reasons:

- The COEA scenario DoD provided calls for 30 percent of the cargo during the first 30 days to be bulk, while our research draws upon the Gulf War experience to assume 50 percent.
- When AMC applies the MASS model to time-phased force deployment data from the DoD, the outsize loads are usually spread across the outsize-capable transports in the manner discussed under Topic 18. As a result, past analysis has shown that the average outsize load carried by outsize transports has been constrained to amounts as low as 25 percent of the average payload (see Topic 18 for some counterexamples).

Other potential contributing reasons seem to be the following:

- The COEA constrained ramp space more tightly (in both the moderate and the constrained cases) than was the case during the Gulf War airlift.

- The COEA, in effect, assumes that C-17 loads are delivered to austere forward-operating locations that are not accessible to the 747-400F, and therefore, the COEA includes the cost of operating additional C-130s for those options that use the 747-400F to compensate for decreases in the C-17's planned procurement of 120 aircraft.
- The COEA assumed activation of the 1993 CRAF Stage II cargo fleet (provides lift equivalent to 65 747s) when the deployment for MRC-East starts and the Stage III cargo fleet (an additional 54 747-equivalent transports) when MRC-West starts some 30 or so days later. The COEA also assumed that the CRAF fleet could carry oversize cargo. We assumed, on the other hand, that the airlift would start with activation equivalent to the CRAF Stage II, which was activated during the sixth month of the Gulf War airlift and provided 28 747-equivalent transports. As was the Gulf War airlift experience, we assumed that CRAF transports carried only bulk cargo.

COEA's Results for Outsize Cargo (Topic 64). The one option addressed in the COEA's report that called for buying only civil-style transports was one (COEA Alternative 19) that adds far more civil-style transports (32 747s plus 83 767s) than our Option E (42 747s). In our analysis, such a large purchase of civil-style transports would yield an unbalanced fleet with insufficient outsize capability for our scenario.² There is also a methodological difference about the way that ALM or MASS-AFM was used to represent the loading of outsize cargo (see Topics 18 and 61).

COEA's Results for Moving Bulk Cargo (Topic 65). We understand that preliminary results from the COEA have compared alternative fleets for their ability to transport bulk cargo more economically. Based upon the significant amount of bulk cargo moved during critical phases of the Gulf War airlift (50 percent during the first 30 days and 63 percent during the sixth month), we think that the comple-

²In our analysis (Chapter Four of Volume 2) we found sufficient outsize capacity in each of the five fleets that we analyzed. However, if we had analyzed COEA Alternative 19, we would have estimated a higher level of capability than the COEA did for the civil-style transports, and consequently would have had an imbalance in outsize versus bulk and oversize capability.

tion and consideration of such results are important to fully informing choices about the right mix.

Sensitivity of Results to Differences in Research Methods (Topic 66)

Comparison of Values That the Methods Produced for Key Parameters. The different research methods produced different values for payloads, utilization rates, and block speeds (see Table E.1 and Topics 26 through 33).

- **Average Mission Payload for the C-17.** The COEA's average payload for the C-17 seems to reflect a critical leg length of about 3,200 n mi³ and an average cargo density that is 29 percent greater than what Air Force planning factors provide for the C-5 and the C-17. For discussion of the research methods that we used to estimate payloads for the C-17, see Topic 26 and Chapter Four of Volume 2.
- **Average Mission Payload for the 747-400F.** The COEA's average payload for the 747-400F appears to reflect a mission in which oversize cargo is loaded on the main deck and bulk cargo is carried in the lower lobe and perhaps at a few main deck pallet positions near the nose and the tail. For discussion of the research methods that we used to estimate payloads for the 747-400F, see Topic 27 and Chapter Four of Volume 2.
- **Average Utilization Rates and Average Block Speeds.** For aircraft utilization rates and block speeds, the COEA used the Air Force's planning factors. For discussion of the research methods that we used to estimate utilization rates, see Topics 29 through 32 and Chapters One and Four of Volume 2.

Table E.1 shows the effects of these differences, and Figures E.1 and E.2 display the results of these calculations. Payload differences are the greatest single influence on results, followed by utilization rates and block speeds. The bottom line is that the COEA assumptions

³During the Gulf War airlift, most C-5 and C-141 missions had critical leg lengths between 3,200 and 3,800 n mi.

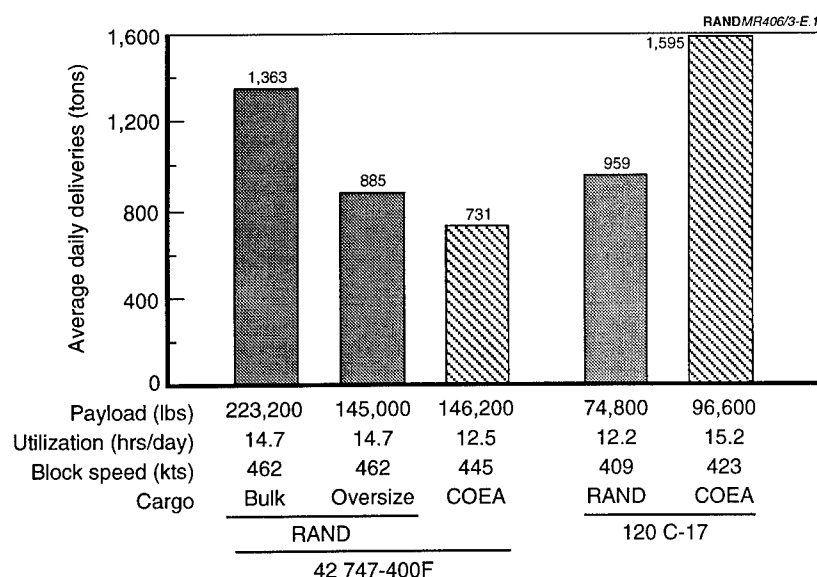


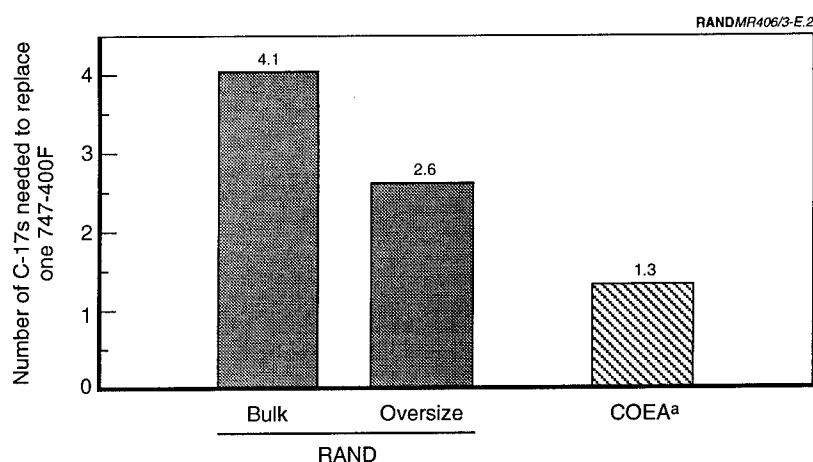
Figure E.1—Differences in Payload, Utilization, and Speed Create Large Differences Between RAND and COEA Estimates for Fleet Throughput

yield a need for 1.3 C-17s to move the same load as one 747-400F, with no constraints on ramp space (Figure E.2). On the other hand, our analysis found that 4.1 C-17s are needed to move the same bulk cargo load as one 747-400F. For oversized mission loads (with one-third of the load being bulk), 2.6 C-17s are needed to move the same load as one 747-400F in our analysis.

FINDINGS FROM OTHER RAND RESEARCH (TOPIC 67)

The findings and conclusions from our research differ from those of other recent RAND work by Lund, Berg, and Replogle (1993) and by Bowie and Frostic (1993), which was supported by the research of Lund et al.

The research of Lund, Berg, and Replogle and our research had different objectives and perspectives. Lund, Berg, and Replogle focused



^aBased upon payloads, utilization rates, and block speeds used in the C-17 COEA.

Figure E.2—RAND and the C-17 COEA Have Produced Significantly Different Assessments of C-17 and 747-400F Throughput Capabilities

on operational effectiveness and the need for flexibility in the military airlift fleet, and it did not consider costs. Our research was strongly influenced by cost considerations, at the request of the Air Force. Both efforts, however, are complementary and can contribute to a more informed consideration of the airlift investment choices facing the nation by interpreting the results in the context of the scenarios and assumptions used in each case.

The main purpose of Lund, Berg, and Replogle (1993) was to offer an analysis of the strategic airlift operation supporting the Gulf War effort by focusing on issues of operational efficiency. Chapter Four of Lund et al., which focuses on implications for the future, addresses several matters, including a comparison of a C-17 fleet to the Gulf War's performance of the C-141 fleet. An additional buy of C-5s and the performance of a CRAF Stage III fleet were considered. Costs were not examined, and the procurement of 747 freighters was not examined. The analysis of the different fleets was based mostly upon the AMC ACAS model, the parking constraints, and utilization rates used by AMC at that time.

The main differences in results between Lund, Berg, and Replogle (1993) and this report lie in three areas: (1) throughput capability of the C-17 fleet, (2) the need for additional outsize airlift capacity, and (3) the recommended course for replacing the retiring C-141s.

Throughput Capability of a C-17 Fleet (Topic 68)

Lund, Berg, and Replogle (1993, p. xv) state: "We estimate that with the 120 C-17s replacing 265 C-141s, the fleet could have deployed at least 30 percent more cargo in the same amount of time as in Desert Shield." Our research shows that a fleet of 120 C-17s can only replace the capacity of two-thirds of the current C-141 fleet of 265 aircraft. The chief reasons for this difference are:

- **Parking constraints.** It appears that the parking constraints in Lund, Berg, and Replogle (1993) only allowed for about half the amount of parking that was used during the peak of the Gulf War airlift. Lund, Berg, and Replogle (1993) report that they assumed a maximum of ten C-5-equivalent parking spaces⁴ for the theater (Southwest Asia), which as they say is roughly equivalent to Dhahran and Jubail. Although ten seems high relative to our previous discussion (Topic 60), in which an average of five were in use, the difference may lie in the distinction between a firm upper limit, say ten, and an average in use, say five. Dhahran and Jubail, together however, received only 67 percent of the arriving transports during the first 30 days and 50 percent during the sixth 30-day period. The result, therefore, seems to be based on an assumed infrastructure that was less capable than that which was in use during the Gulf War airlift.
- **Ramp space availability and use.** Furthermore, at the time of our research, views within AMC were divided about whether ramp space or fuel was the binding constraint during the Gulf War airlift. Early in our research, the AMC/XP (Plans) staff informed us that they were concerned that fuel rather than ramp space may have been the binding constraint during the Gulf War airlift. The AMC/XR (Requirements) staff maintained that ramp space remained the dominant consideration for evaluating the

⁴The spaces, of course, would be used by all transports participating in the airlift.

C-17. Regarding the comparative use of ramp space by different aircraft supporting a major strategic airlift operation, we believe the important measure of merit is the amount of payload delivered per unit of ramp space hours consumed. With such a measure, the differences between the C-17 and the C-5 (and other transports) become small and very sensitive to what one assumes about parking density and times for loading and unloading.

- **Utilization rates.** Like the COEA, Lund, Berg, and Replogle (1993) assumed that the Air Force's planning factor of 15.2 hours per day for the C-17 was a reasonable representation for the performance of the C-17 fleet. We estimated that utilization rates would be 12.2 hours per day (see Topics 29 through 32).

Need for Additional Outsize Airlift Capacity (Topic 69)

In the observations and recommendations section, Lund, Berg, and Replogle (1993) presents the view that more outsize capability is needed, because (1) the C-5's reliability problems result in relatively low availability (68 percent in the Gulf War); (2) the demand for C-5 missions during the Gulf War exceeded the supply; and (3) the C-5 requires a lot of ramp space.

Our research shows that additional outsize capacity is not needed, assuming that the DoD implements needed C⁴ improvements to allow efficient use of the current C-5 fleet.

The chief causes of this difference in results are:

- **Policy options for addressing availability issues.** Our research explicitly modeled the effect of reliability and maintenance on the availability and utilization rates for each transport. For all of the transports, we explored policy options for increasing availability and utilization. One promising class of options is to reduce the number of ground stops by changing policies regarding the changing of crews and by using aerial refueling when available.
- **Analysis of the Gulf War applications of the C-5.** During the Gulf War airlift, C-5s were occasionally needed to move outsize materiel, but were sometimes unavailable, because they had been

assigned to carrying other types of loads.⁵ Since the completion of Lund, Berg, and Replogle's research, we have learned that these other loads were often palletized materiel that could have been readily carried by a civil-style transport.

Recommended Course for Replacing the Retiring C-141s (Topic 70)

In the observations and recommendations section, Lund, Berg, Replogle (1993) report that C-141 replacement is essential to maintaining the capability to conduct an Operation Desert Shield-size deployment in the future without crippling the civil sector. It adds: "If the C-17 program continues on course, the issue can probably be put to rest."

Our research concludes that a change in course to a civil-style transport may be necessary to cut costs.

The chief causes of this difference in results are:

- Consideration of the costs of alternative fleets
- Consideration of options where the DoD would operate civil-style transports.

⁵From the information that it collected during the airlift, the Air Force is unable to identify the amount of outsize cargo, if any, that was delivered by each mission. To construct estimates of the total outsize cargo delivered each month, Air Force analysts have reviewed the units delivered and the amount of outsize those units usually require.

USING THE RESEARCH RESULTS TO INFORM FUTURE CHOICES

Although any research effort is necessarily limited by its scope and its time of completion, the enduring value of its results lies in its continuing relevance to future policy decisions. Because many of the tough choices lie ahead, many of the questions addressed by the research remain open. The purpose of this appendix is to illustrate how the results of the research can be used to inform future choices.

Notwithstanding the many changes that are occurring, it appears that, in many cases, such as the following, it will be possible to adapt our research results to help inform future choices as the DoD continues its efforts to find the right mix of military and civil airlift. To illustrate such adaptation, we consider the following events, changes, and ongoing activities:

- **DoD's evolving assessment of airlift requirements.** While our research focused on a single MRC, the DoD has decided since the completion of our work that it must support two almost simultaneous MRCs. Moreover, the DoD continues to revise its assessment of the airlift requirement. Recent assessments show an increase in the amount of materiel, including outsize and over-size, that must be delivered by airlift during the early weeks.
- **DoD's continuing revisions to the CRAF program.** Although our research found little prospect for increasing CRAF participation, the DoD is continuing to implement changes to the CRAF program that are intended to maintain the support of the air carriers while increasing the amount of airlift provided by Stages I and II.

- **The CINCs' decision on airlift requirements.** Although our research considered civil-style transports as a suitable substitute, albeit with a loss in flexibility, the CINCs have decided that the C-141 should be replaced with a military-style transport to maintain needed military flexibility.
- **DoD's nondevelopmental airlift aircraft program.** To develop a hedge against the possibility of further difficulties with either the affordability or the timely production of a satisfactory design, the DoD has instituted the nondevelopmental airlift aircraft program to start exploring alternatives to the C-17 that would not require a development program.
- **The Defense Acquisition Board's C-17 decision.** Although Option E defines a situation in which no C-17s would be included in the strategic airlift fleet, the Defense Acquisition Board has decided that the DoD will procure at least 40 C-17s.
- **The retirement schedule for the C-141.** While our research assumed that one-third of the C-141 fleet would be retained in service, following extensive modifications to prolong its service life, it now appears that the entire fleet will be retired by as soon as the year 2005.

DOD'S CONTINUING ASSESSMENT OF AIRLIFT REQUIREMENTS (TOPIC 71)

In the strategic airlift mission area, perceptions of requirements and assessments of the level and mix of loads to be sent by air can change faster than a short-term research effort can complete its work. Although shifts in broad guidance tend to remain stable for a number of years, once a shift occurs (such as adoption of the policy to support two MRCs), it can take a couple of years of DoD analysis to stabilize assessments of the total forces to be moved and the assessment of the loads those forces need over time. Meanwhile, as the force and load assessments are evolving, other analyses need to explore how the loads should be divided between prepositioning (ashore and afloat), sealift, and airlift. By the time a stabilized assessment of the loads to be transported by airlift emerges, several years may have passed. Needless to say, by that point, with fuller appreciation of the costs of the former policy guidance, and facing further declines in

defense resources, there is the possibility of a further adjustment to policy, whereupon the process begins anew.

DoD Has Added a Second MRC and Increased Airlift Needs Since 1992

Shortly after the completion of DoD's 1992 Mobility Requirements Study, there was a major shift in the Defense Planning Guidance with the adoption of the concept that the armed forces should be sized, trained, and equipped to deal with two nearly simultaneous MRCs.

Realization of mobility limitations forced planners to adopt a "nearly simultaneous" strategy instead of a simultaneous approach. A key assumption is that forces put in place for the first contingency will have sufficient equipment either to conclude operations before the second contingency begins or to hold their positions while mobility resources are shifted to placing forces in theater for the second contingency. Given assumptions about the forces probably required for a first contingency and given limitations on mobility resources, planners believe that the mobilization for the second contingency could occur not sooner than about 45 days after the mobilization commences for the first contingency.

Review of the load plans shows that the two-MRC case can be viewed as simply an extension of the single-MRC case addressed by our research, plus an increase in the flow of bulk cargo midway through the 90-day period of interest.

DoD's 1993 assessments of the loads to be carried by airlift, which served as the basis for the COEA, called for moving 550,000 tons to two theaters in 90 days. For the Gulf War, nearly the same amount was delivered over six months.

For the first theater (MRC-East), in the Middle East, airlift needed to deliver 200,000 tons during the first 30 days. The average daily delivery rate of 6,700 tons is three times that of the first 30 days of the Gulf War airlift and almost twice the rate for the peak month of that airlift.

When mobilization for the second nearly simultaneous contingency commences, virtually the entire military airlift fleet must be swung to

support that effort. Doing this requires time and resources to reposition and sustain the airlift fleet for the second contingency.

Additional civil transports supplied by a Stage III activation of the CRAF would ostensibly be available to help sealift sustain support for the first theater. Thus, from the perspective of the military airlift fleet, the main difference in supporting the two-contingency scenario instead of the single-contingency scenario addressed by our research is that, after 45 days, the locations for the APODs change and more civil transports are activated to provide sustaining support for the first set of APODs.

DoD Has Increased Airlift Needs Since 1992

DoD's most recent assessment calls upon airlift to deliver about 8,000 tons per day for the first 21 days. At day 45, the second MRC starts. For its first 21 days, airlift needs to maintain average daily delivery rates to both theaters that total about 9,000 tons per day. However, achieving even 70 percent of these daily rates will be difficult, given our assessments of achievable utilization rates and payloads and recognizing other commitments that the airlift must satisfy. Moreover, even achieving 70 percent of these daily rates depends on the participation of the equivalent of 65 CRAF 747 cargo transports from the start of the first mobilization and a total of 116 747 cargo transport equivalents starting on day 45.

The DoD's adjustments, according to our research findings, place it in a situation where there is a 30-percent shortfall in airlift capacity for the DoD's 1994 projection for the two-MRC scenario. The DoD has two options: It can either increase the capacity of the military airlift fleet, or it can shift more of the loads to prepositioning and/or fast sealift. Such alternatives could also be used to lessen the reliance on CRAF.

In either event, the need for economic efficiency in DoD's investment in airlift seems to have become even greater in view of changing perceptions of the needs for airlift. With the postulated two-MRC requirement for airlift, the results of our research and the new research methods we have developed remain as relevant as they were in 1992.

DoD Is Now Projecting a Lower Proportion of Bulk Cargo Than Was Delivered During the Gulf War Airlift

DoD's recent assessment that bulk cargo may be as low as 25 percent during the initial weeks has two implications for our research results.¹ First, outsize capacity under Option E would be sufficient only if the C-5s are efficiently used for outsize missions and if outsize mission loads are prepared to maximize the outsize materiel that units place on each C-5.

Second, for the oversize materiel, about two-thirds of it would have to be delivered by the 747-400F fleet under Option E. Recent analyses and tests for the DoD indicate that the 747-400F could accommodate more than 80 percent of the Army's oversize equipment if the aircraft's floors were strengthened and if either its aft side door (10-ft vertical clearance) were widened or if the Army reverts to its former policy of buying trucks with collapsible cabs so that they can fit through the nose door (8-ft vertical clearance).

In view of the recent adjustments and in light of our research findings, there seem to be some inconsistencies that may warrant some DoD attention. A beneficial review might address both the basis for DoD's assessment that bulk cargo may be as low as 25 percent and the reasons why the Gulf War experience was twice that projection during the critical first 30 days.²

Although it might seem that the Gulf War airlift delivered so much bulk materiel because most of the outsize materiel was delivered by sealift, DoD's plans call for the use of even more fast-sealift ships and more prepositioning than was available for the Gulf War. Thus, we think it may be useful for the DoD to reexamine this area and to consider whether the way that the DoD categorizes cargo (outsize,

¹In recent analyses, the DoD has sought to select airlift and prepositioning programs that complement one another to provide for military requirements at the least cost. DoD staff recently reported that their analyses to date have found that, if we preposition the right mix of equipment and supplies, the cargo to be moved early in a deployment is predominately oversize and outsize. Our analysis did not examine prepositioning.

²The bulk cargo assessment seems low, because bulk cargo includes any materiel that can be placed on a 463L pallet with an envelope measuring 9 ft long, 7.3 ft wide, and 8 ft high.

oversize, and bulk) is the most appropriate approach for maximizing the effective use of various types of aircraft. In particular, the capabilities that a civil-style transport offers may be better exploited by the DoD with a different view of load categories. Different-size pallets and the use of containers³ may also allow fuller exploitation of the range capabilities of the civil-style transports.

A Hypothetical Scenario Is Less Sensitive to DoD's Changing Assessments

Because the DoD's articulation of airlift requirements was in a state of flux at the time of the research (1992), we developed a hypothetical airlift scenario to test the operational merits of alternative mixes of transports. This has contributed to the relevance of our results, because they are not tied to a specific assessment of the loads and thus subject to change.

Moreover, at least thus far, we have seen no changes in the DoD's evolving assessments of what would be moved by airlift that would seriously alter the relative abilities and costs of the alternative fleets examined by our research. In terms of the evolving perceptions of the needs to conduct strategic airlift, our research results continue to provide a meaningful comparative analysis of fleet options.

By using a hypothetical scenario to test alternative fleets, we were able to apply what seems to be a tougher test than what has thus far emerged from the evolving articulation of DoD's requirements for

³For example, about half of the materiel for the light divisions (airborne and light infantry) can be "containerized" for shipment by sea. A 747-400F can also carry containers nearly as large as those used for shipment by sea. One promising container size for military applications may be the one that is 20 ft long, 8 ft wide, and 8 ft high. Although the use of such containers would be a departure from the DoD's standard approach, which is based upon the 463L pallet, DoD may find—as the private sector has—that the use of proper containers can lower the total costs of transportation. Another potentially promising container is 10 ft long, 8 ft wide, and 8 ft high. This container, which is slightly contoured to fit the 747-400F cabin, allows air carriers to make maximum use of the 747-400F's volume. A study of how units might use such containers to use a transport like the 747-400F more effectively could provide further important information for future decisions. If use of such containers appears promising, other research would need to explore whether it is cost-effective to assimilate such containers and wider 747-400F doors within the DoD's larger transportation system.

strategic airlift. Philosophically, we believe that a tough test is appropriate, because inclusion of a civil-style transport in the military's strategic airlift fleet would be a major shift that needs to meet a high standard in terms of operational expectations.

DOD'S CONTINUING REVISIONS TO THE CRAF PROGRAM (TOPIC 72)

The DoD is in the process of implementing and evaluating several changes to the CRAF program that could have a profound effect on the future composition and dependability of the CRAF. The three potentially most significant changes being implemented are:

- **Linkage of CRAF commitments to General Services Administration (GSA) business.** To level the playing field, DoD is requiring all air carriers to join the CRAF to qualify for government travel business administered by the GSA and to qualify for the government's small-package business.
- **Increasing the size of CRAF Stage II for cargo.** CRAF Stage II now includes twice the airlift capacity than had been called for by the definition of Stage II that was in force during the Gulf War airlift.
- **Plans to use the Bilateral Commission.** Regarding the threats to their markets from foreign air carriers during an activation, the DoD has identified the bilateral commission process as the chief mechanism to protect market shares during an activation. However, the effectiveness of such a process for resolving damages and restoring market positions remains to be demonstrated. Until then, U.S. air carriers are not likely to place great confidence in that process.

The number of civil-style transports that the DoD might decide to operate (if any) could be affected in significant ways, depending upon the outcomes from these changes.

If the changes achieve all of the intended effects without introducing adverse side effects, then the CRAF could be depended upon for a substantial amount of airlift capacity when needed. Such a positive outcome might make even greater dependence on CRAF a possibil-

ity. In such a case, the DoD may not need to operate any civil-style transports.

On the other hand, if the changes falter and economic considerations dampen real commitments to the CRAF,⁴ the amount of civil airlift that can realistically be summoned from the civil sector without incurring unacceptable economic and political consequences may fall far short of current plans. Such a negative outcome could reduce CRAF's dependability and perhaps its fleet size. In this case, the need for DoD operation of civil-style transports becomes more compelling.

Unfortunately, the full effects of the changes may not become apparent for at least a few years and perhaps not fully until the next activation occurs.

One of our research findings was that the large air carriers, who supply much of the Stage II capability and most of the Stage III capability, are generally adversely affected by an activation of the CRAF, because they must pull resources from markets that were difficult to develop and that are vulnerable to competitors during any period in which service is reduced.

Some carriers have indicated resistance to the connection of GSA business to CRAF participation. Whether that resistance someday results in a court ruling remains to be seen. In any case, a number of implementation matters remain to be addressed, for example:

- For some carriers, the government needs more than the 15 percent of their capacity that is linked to the right to obtain GSA business.
- Other carriers may have none of the aircraft qualified for international flight that the government needs.

⁴By real commitments, we mean those that the DoD can reasonably expect to execute to support its operations during major regional contingencies, whether the contingencies occur singly or in nearly simultaneous pairs. How all of these factors play out depends upon the extent to which the air carrier's legitimate concerns are really addressed by the DoD's changes to the CRAF program and how the air carriers judge those changes and choose to respond.

Moreover, although the government has doubled the size of CRAF Stage II for cargo transports, a single carrier was responsible for almost 40 percent of this capability in 1994. Such concentration of dependence on a single carrier risks a situation in which that carrier would be forced to seek relief from its commitment during a crisis.

This raises the question of how meaningful large commitments to the CRAF are, especially in view of the Gulf War experience, in which Stage II activation was deferred until after the Christmas business peak and Stage III was not activated despite the size of the bulk cargo backlog just prior to the start of hostilities. Air carriers may be tempted to exercise their political influence to win some relief from their commitments because of the economic hardship that they would incur. They may also be calculating that activation of the CRAF is unlikely.

Certainly, it would seem that frequent activation of the CRAF would have the potential to seriously dampen commitments unless satisfactory mechanisms are found to adjust to the adverse consequences. Whether such mechanisms are now in place remains to be seen.

CINCS' DECISION ON AIRLIFT REQUIREMENTS (TOPIC 73)

In August 1993, the CINCs expressed a strong preference for the procurement of a new military-style transport, in particular, the C-17. That preference reflects an operational view that must be given serious consideration in the policy determination process within the DoD. That process, however, must also struggle with the costs of alternative means of satisfying all the CINCs' needs.

Because the Services, and not the CINCs, are primarily responsible for managing the application of the DoD's resources across mission areas, the CINC perspective is one part of a larger resource-allocation process. Consequently, our research results may be even more important to the DoD policymaking process in view of the CINCs' expressed preference, because it reflects an economic perspective that is also part of the larger total application of defense resources.

The unanswered question is whether the CINCs' support for flexibility would remain as high if fiscal limitations meant that capacity

must be sacrificed to provide the CINCs' preferred level of flexibility. Our research findings shed some light on the linkage between costs and capacity. Future DoD decisions will determine the extent of fiscal limitations for the strategic airlift mission area. Given our research results and awareness of such limitations, the CINCs will be able to make more informed decisions about their preferences for flexibility versus capacity.

DOD'S NONDEVELOPMENTAL AIRLIFT AIRCRAFT PROGRAM (TOPIC 74)

DoD is involved in several efforts to prepare for a November 1995 decision regarding further procurement of the C-17 and/or other transports. DoD intends to further evaluate the C-17's aircraft performance, ability to use austere airfields, reliability, maintenance, and production costs. DoD is also planning to evaluate further the changing worldwide infrastructure that is required to support airlift operations, as well as alternative airlift fleet options. As part of these efforts, DoD has established the Nondevelopmental Airlift Aircraft (NDAA) program to solicit and evaluate information about alternative transports.⁵ Information is being acquired regarding the loadability of civil-style transports, including loading and unloading times and the ability to carry oversize materiel.

DoD's ongoing efforts have the potential to clarify or verify several key matters addressed by our research. These include the capability of the 747-400F to carry oversize materiel and the austere airfield capabilities of the C-17. Such efforts have the potential to significantly contribute to forthcoming choices about the right mix.

DAB'S C-17 DECISION (TOPIC 75)

During the fall of 1993, the DoD's Defense Acquisition Board reviewed the status of the C-17 program and decided to place the program on probation, settle outstanding claims made against the gov-

⁵An early draft of the operational requirements document for the NDAA suggests that the DoD may use the NDAA program to solicit competing offers from industry and to enter into a source selection process. The results of our research should be of interest to all of the participants in that process.

ernment by the prime contractor, commit to the production of no more than 40 aircraft, and give the prime contractor until the fall of 1995 to rectify design deficiencies, reduce production costs, and demonstrate an ability to meet a production schedule.

In view of this DAB decision, Option E may no longer seem relevant. However, the DoD may or may not elect to remain on its present course of action. Depending upon contractor performance and budget pressures, the DoD may decide that it must change course before the delivery of the fortieth aircraft. (As of October 24, 1994, 15 had been delivered.)

Or, at some future point, the DoD may decide to assign the C-17s then delivered to tactical airlift duties where application of its in-theater strengths (such as movement of outsize equipment) might be maximized and where the consequences of its intertheater weakness (range-payload capability) might be minimized.

C-141 RETIREMENT SCHEDULE (TOPIC 76)

At the time of the research in 1992, the Air Force intended to extend the life of about one-third of the C-141 inventory to continue the service of 80 aircraft (PAA) to beyond the year 2010. We examined the scope of work required and the estimated costs and benefits of such a course of action. Three factors seemed to provide overwhelming support for such a course, even though there were risks of running into heretofore unknown problems that would escalate the costs:

- **Costs.** The costs were an order of magnitude less than the cost of procuring additional C-17s (beyond the Air Force's then-planned buy of 120 aircraft).
- **Capability to Air-Drop a Brigade.** For the brigade airdrop mission, about 80 C-141s seemed liked a satisfactory number of aircraft. (It would require from 80 to 98 C-17s to drop the same quantity of paratroopers, depending upon how many are carried by the C-141.)
- **Ability to Maintain the Capacity of the Military Airlift Fleet.** According to our analysis, the procurement of 120 C-17s would replace the capacity of only two-thirds of the C-141 fleet. Thus,

retaining 80 PAA C-141s was necessary to avoid a decline in airlift capacity.

We decided for these reasons to keep 80 PAA C-141s in the base case that was used with each of our five options (A through E).

Since the completion of our research, the Air Force and the DoD have decided that the evidence regarding the condition of even the least-worn third of the C-141 fleet is such that it would be imprudent to extend service life. Accordingly, all C-141s are now scheduled for retirement by the year 2005.

This decision raises a couple of questions: First, what should the DoD do about the impending retirement of the last third of the C-141 fleet? Second, what is the remaining relevance of our analysis of alternative fleet mixes in view of the fact that we assumed the availability of 80 PAA C-141s?

DoD's Policy Options for Dealing with the Retirement of the Last Third of the C-141 Fleet

DoD has a variety of options that may be worthy of consideration, given the evolving fiscal situation:

1. **Reconsider life extension.** Reconsider the decision to not try extending the service life of any C-141s. This is a long shot, but, given evolving fiscal realities, it may deserve one more examination.
2. **Explore buying 94 new C-141s.** Explore the possibility of manufacturing a modernized C-141. This is another long shot, but, given how well this aircraft has served, it may be worth a quick look.
3. **Buy 60 C-17s.** Procure 60 C-17s to replace the capacity lost in the retirement of the last third of the C-141 fleet. Currently, the DoD is already committed to buying 40. Increasing that procurement to 60 aircraft would take care of the last third of the C-141 fleet.
4. **Buy 60 C-5s.** Reopen the C-5 production line and procure 60 additional C-5s to replace the capacity lost in the retirement of the last third of the C-141 fleet.

5. **Buy 20 modified 747-400Fs in addition to the 42 in Option E.** Strengthen the floor of the 747-400F (and possibly enlarge the aft side door) to carry large and heavy oversize equipment to compensate for part (perhaps all) of the oversize capacity lost in the retirement of the last third of the C-141 fleet.
6. **Do nothing and accept a lower capacity.** Buy no additional aircraft for strategic airlift and accept the reduction in military airlift capacity.

Under the last two options, there would be a need to deal with the brigade airdrop requirement. DoD could consider four possible solutions: (1) use C-130s, (2) use C-5s, (3) buy a military-style transport designed and produced in another country, or (4) reconsider the requirement. Regarding the third option, DoD might consider joining the European efforts to develop a common transport.

If the DoD found it advantageous to select aircraft other than the C-17 to replace all of the C-141 fleet, that would raise a question about what it could do with those C-17s that had already been produced. Depending upon test results regarding the question of airfield access, and depending upon intratheater needs for moving outsize equipment by air, the C-17 might be devoted entirely to intratheater airlift.

Adapting the Research Options and Results to Address the Need to Replace All C-141s

Even though our base case assumed the inclusion of 80 PAA C-141s, there are a couple of ways in which our analysis of Options A through E can contribute to future decisions that the DoD will be making about the right mix:

- For example, the question of how to best replace the C-141 fleet could be divided into two questions: one addressing the two-thirds of the fleet that we have already analyzed and the other addressing the last third that remains to be analyzed.
- Or the intermediate results for Options A through E could be used to estimate the relative performance and costs for new op-

tions that would address the need to replace the last third of the C-141 fleet.

For example, consider how Options A and E might be adapted to address the need to replace all of the C-141s. Figure F.1 illustrates this point by addressing two of the possibilities that might be considered. Option AA replaces the entire C-141 fleet with C-17s, while Option EE uses 747-400Fs. We have not tried to update these results to reflect current cost estimates, although we have made adjustments to delete all costs covered by defense budgets approved through FY 1995.

However, the use of the COEA parameter values (Table E.1) yields a much lower estimate of the cost difference (Figure F.2). According to the COEA parameter values, 122 C-17s are sufficient to replace the capacity of the entire C-141 fleet. So, with the COEA parameter values, the cost difference between buying C-17s and 747-400Fs is only about \$7 billion and not the \$29 billion suggested by Figure F.1.

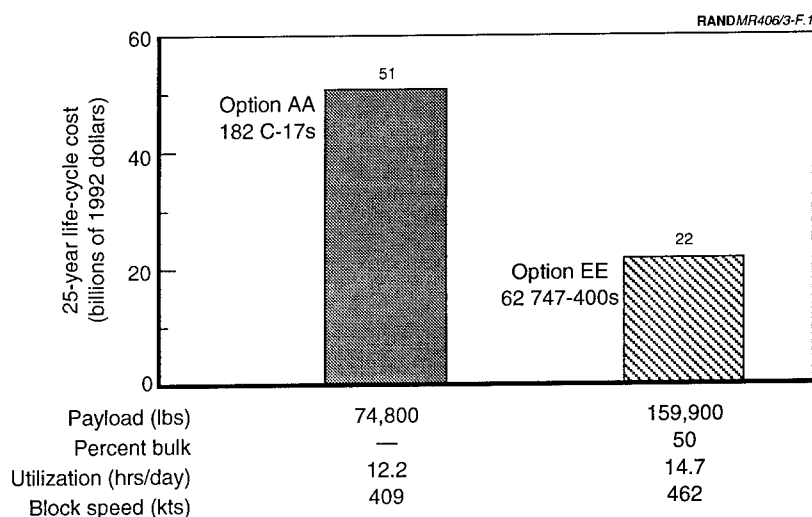


Figure F.1—Life-Cycle Costs for Replacing the Entire C-141 Fleet

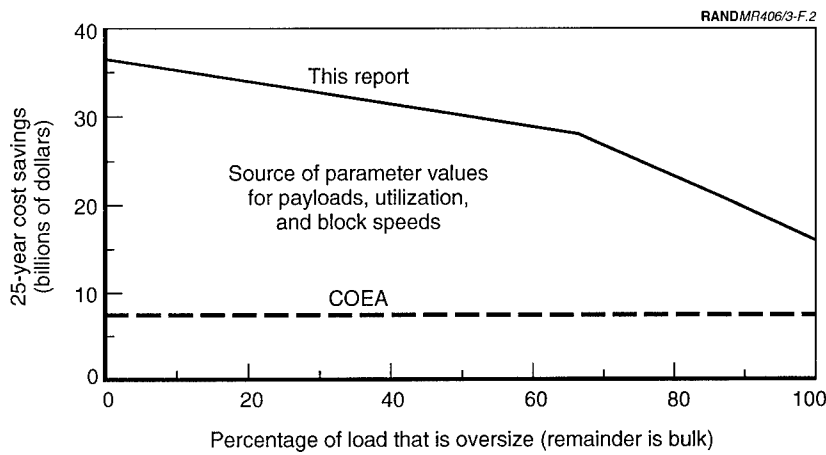


Figure F.2—The Cost Savings Due to Replacing the Entire C-141 Fleet with 747-400Fs Instead of C-17s Is Sensitive to the Load Mix and Parameter Values for Payload, Utilization, and Block Speed

There are three important messages:

- First, cost differences are very sensitive to the methods used in calculating values for four critical parameters (payload, utilization, load mix, and, to a lesser extent, block speed).
- Second, using only military-style transports to replace the capacity of the entire C-141 fleet is significantly more costly, by our calculation methods, than the alternative of including civil-style transports in the military airlift fleet. However, it would retain airdrop capability.
- Third, substituting a civil-style transport for the C-141 comes at the cost of reduced military flexibility. Option EE, therefore, despite its fiscal attractiveness, may be rejected on the grounds that it requires too great a sacrifice in military flexibility.

IMPORTANT OPEN ISSUES

The question that our research addressed (Figure G.1) remains unanswered, notwithstanding significant findings¹ in many areas that have begun to shape the probable nature of the right mix. To complete the journey and to find the best estimate for the right mix, DoD needs to pursue open issues in four areas: (1) fleet capability assessment, (2) fleet composition, (3) aerial refueling, and (4) fleet operation. To help resolve or narrow these issue areas, this appendix presents a set of 15 prospective initiatives that the DoD should consider pursuing.

FLEET ASSESSMENT ISSUES (TOPIC 77)

How Should Planning Factors Be Developed for Aircraft Parameters?

How can the DoD narrow the discrepancies in estimates for fleet performance that are being caused by differences in estimated values for three aircraft parameters: payloads, utilization rates, and block speeds? Because these parameters have some significant interdependencies, it is important to use consistent methods and assumptions in estimating their values. For example, increasing the number of stops for refueling may yield shorter flight distances between stops, in which case payloads can be increased. On the other hand, making more frequent stops reduces block speeds and increases the

¹See Chapter One of Volume 1 for a summary of the findings.

The Question

What is the most efficient mix of civil and military airlift resources that will provide sufficiently robust capabilities across the range of situations for which the Air Force must be prepared?



Our Research Findings

- Capacity of the 1992 airlift fleet
- Changes in demands for airlift
- Improve application of civil airlift
- Improve application of military airlift
- Closure of the C-130 production line
- Analysis of alternative fleet mixes



Issues for the DoD to Address

Fleet Assessment Issues

1. How should planning factors be developed for aircraft parameters?
2. How should planning factors be developed for load parameters?
3. How should planning factors be developed for CRAF's availability?
4. How should fleet flexibility be factored into the analysis and decisions?

Aerial Refueling Issues

9. How much can aerial refueling increase daily deliveries?
10. Can air crews be repositioned to help aerial refueling increase deliveries?
11. Can payloads be increased to help aerial refueling increase deliveries?
12. How should the costs of aerial refueling be allocated?

Fleet Composition Issues

5. How should the technical base regarding airfield access be improved?
6. Would the government be allowed to operate a fleet of civil-style transports?
7. Should the government buy used 747s instead of the 747-400F?
8. How should the C-130 configuration be changed for future procurement?

Fleet Operational Issues

13. Are command, control, communication, and computers improving sufficiently?
14. Can AMC and airlift users jointly improve loading efficiency?
15. Could APOEs be consolidated to increase daily deliveries?

Figure G.1—Issues the DoD Needs to Address to Find the Right Mix of Military and Civil Airlift

ground time, which in turn reduces utilization rates. Moreover, as already discussed, these aircraft parameter values depend upon many other factors, including what is being delivered, whether aerial refueling is available, and various servicing and maintenance matters that influence ground times.²

Initiative 1. The DoD should conduct a series of workshops to help design, oversee, and evaluate a set of analyses and experiments that would produce the information that is needed to establish an appropriate set of methods and assumptions. These methods and assumptions would then be used with a set of specific scenarios to estimate sets of planning factor values consistently for aircraft payloads, utilization rates, and block speeds that are appropriate for analyzing the performance of alternative fleets in those specific scenarios.

How Should Planning Factors Be Developed for Load Parameters?

How can the DoD narrow the discrepancies in fleet-performance estimates that are caused by different estimates for the load parameters that represent the time-phased mobilization needs? Accurate evaluation of the capability of an airlift fleet requires good visibility of the time-phased mobilization needs of individual units. In fact, however, it is not at all clear what personnel and materiel (by cargo category) must be delivered in the following combinations: (1) together on individual aircraft, (2) together on a group of aircraft that need to arrive within a specified time period, and (3) over time for the unit to achieve specified levels of combat-relevant capability. By improving analysts' visibility of and understanding in these areas, DoD can obtain better analyses of how alternative fleets perform in the time-phased delivery of combat forces.³

²Matters that need to be included are the average deck loads that can be achieved by different transports and the percentage of the oversize materiel that can be delivered by civil-style transports.

³Additional matters that need to be examined include the effect of prepositioning on the amount of materiel that would be delivered by airlift and the portion of that materiel that could be delivered by civil-style transports.

Initiative 2. To improve the ability of airlift planners and airlift analysts to make more accurate evaluations (of the load mixes to be expected for individual units, the level and composition of airlift needs, and the adequacy of specific airlift fleets), the DoD should consider sponsoring a series of meetings to review, refine, and monitor efforts aimed at improving the load information that will be available in the future for individual units.

How Should Planning Factors Be Developed for CRAF Availability?

How can the DoD narrow the discrepancies in fleet-performance estimates that are caused by different estimates for the availability of the CRAF? An accurate estimate of the least-cost mix of airlift resources requires an accurate assessment of the availability of the CRAF (including timing). Thus, for guiding fleet investment decisions, it is important to set planning factors for CRAF's availability that are prudent and realistic. This is difficult, because the activation of the CRAF's various stages depends upon how people, including the president, would react to perceptions of airlift needs during the course of a crisis. Although part of CRAF can safely be assumed to be available, because the small air carriers tend to be eager to provide emergency airlift services, the large air carriers lack such interest.

Initiative 3. To strengthen its basis for setting planning factors for reasonably achievable levels of CRAF availability for different situations, the DoD should more fully examine the implications of activating CRAF Stages I, II, and III. DoD should also estimate the situations under which it would probably be reasonable to plan upon such activation, because the disruption caused by activation would probably be seen as less important than the national interest at stake.

How Should Fleet Flexibility Be Factored into the Analysis and Decisions?

Because a complete evaluation of the operational suitability of an airlift fleet needs to include consideration of both capacity and flexibility, and because there is a trade-off between flexibility and capac-

ity for a fixed level of spending, does the DoD need to better integrate operational and fiscal perspectives in finding the right mix? Capacity can be calculated with fair precision, given values for the key parameters, but fleet flexibility does not lend itself very well to quantitative methods. Moreover, because judgments about the relative needs of investing in flexibility versus capacity are operational matters, the unified command CINCs should have a role in the formulation of such judgments. On the other hand, the DoD's resource allocation process inevitably produces limits on spending for strategic airlift. To integrate the CINCs' perspectives earlier in that process, we offer the following thoughts:

Initiative 4. To explore more timely integration of necessary operational and fiscal perspectives in the decisionmaking process, the DoD should consider adopting an approach like the following: (1) establish several alternative spending levels for the airlift mission area, (2) design and analyze alternative fleet mixes for each budget level, and (3) provide the unified command CINCs the opportunity to express their preferences for what would be the right mix at each budget level.

FLEET COMPOSITION ISSUES (TOPIC 78)

How Should the Technical Base Regarding Airfield Access Be Improved?

Because the C-17's flexibility in accessing airfields is one of its most valuable characteristics, how does the DoD need to improve the technical methods and information in this area to narrow the range of estimates about the extent to which the C-17 is uniquely able to access makeshift landing strips and austere airfields? The C-17's value in the tactical airlift role depends on its ability to use makeshift landing strips and austere airfields. Forthcoming test results will be very important in clarifying the C-17's capabilities and comparing them to the known performance of the C-130. Moreover, because our analysis shows that the C-5 and the C-17 have comparable ability to use airfields suitable for major APOD operations, it is also important for forthcoming test results to clarify differences between the C-5 and C-17. To ensure that a timely and sufficient set of tests are conducted, the DoD could pursue the following initiative:

Initiative 5. To resolve the uncertainties regarding the airfield-access capabilities of transport aircraft, the DoD should consider convening a group of technical experts to review methods, data, and test plans to decide whether it would be productive to pursue additional technical work. If so, this group should participate in the formulation, execution, and evaluation of such work.

Would the Government Be Allowed to Operate a Fleet of Civil-Style Transports?

Even though government operation of civil-style transports may be key to achieving an affordable mix, how does the DoD need to reduce the uncertainty that has been raised by the view that the government would not be allowed to operate such transports? For example, air carriers are concerned about losing business. Supporting the proposition that the civil air carriers should operate the civil-style transports is the view of some analysts that the government can more economically enlist in the CRAF (rather than operate such aircraft itself) whatever capacity it needs by simply paying enough of an annual subsidy. Under such a premise, there is the possibility that the government might arrange for the private sector to own and operate the 42 747-400Fs our analysis considered as an alternative to 120 C-17s. The cost of such a CRAF arrangement might be significantly less than the 25-year cost of \$15 billion (1992 dollars) that we have estimated for government ownership and operation of such a 747-400F fleet. However, such considerations would need to address issues of both cost and the flexibility that underlie government operation of such a fleet. For example, the Air Force can position its transports and initiate airlift operations without creating the visibility that comes from a large activation of the CRAF. Moreover, the Air Force can depend upon its ability to direct its transport fleet to go into harm's way as events may dictate.

Initiative 6. The DoD should clarify the potential legal and political impediments that may restrict its ability to own and operate a fleet of civil-style transports.

Should the Government Buy Used 747s Instead of the 747-400F?

Given the many used 747s that are available for sale, and given the successful experience of air carriers who have modified older 747s to carry freight, should the DoD procure used 747s instead of new 747-400Fs? In answering this question, the DoD needs to consider (1) that significant investments would be required to extend service lives and to convert passenger aircraft to a freighter configuration; (2) that the operating and support costs for used 747s would be higher because of the age of systems, higher fuel consumption, and larger flight crews (three versus two for the 747-400F); and (3) that the 747-400F could carry larger loads over greater distances. In many situations the 747-400F could fly nonstop from airports in the United States to theater APODs. Although we rejected the possibility of the government buying used 747s in our analysis, a second and fuller examination may be warranted.

Initiative 7. If incorporation of a civil-style transport into the military airlift fleet appears to be a viable alternative, the DoD should initiate a complete cost and operational effectiveness evaluation for the procurement of used 747s instead of the new 747-400F model.

How Should the C-130 Configuration Be Changed for Future Procurement?

Assuming that the DoD chooses to retain a production line for C-130s, what configuration changes are appropriate investments in the future capabilities of the C-130, and might any of those capabilities provide suitable alternatives to capabilities now provided by the C-141? Although our research found potential value in redesigning the C-130's landing gear to increase its access to makeshift landing strips and austere airfields, other changes are potentially more important to maintaining strategic airlift capabilities through austere times. For example, configuration changes, such as the addition of aerial refueling, would increase the C-130's range and make it a more suitable substitute for the C-141 in such missions as the brigade air-drop and the rapid offload on runways under threatening conditions.

Initiative 8. The DoD should consider a broad review of future needs and configuration options for the C-130, with special attention to the possibility of substituting the C-130 for the C-141 for some missions.

AERIAL REFUELING ISSUES (TOPIC 79)

How Much Can Aerial Refueling Increase Daily Deliveries?

Because the ability of aerial refueling to increase daily deliveries is very sensitive to the routes that transports are assigned, should policies governing the routing of transports be revised to maximize the ability of aerial refueling to increase daily deliveries? For example, if a policy goal is to minimize the number of stops, aerial refueling has its maximum opportunity to increase daily deliveries. Such a goal, however, is in conflict with the current practice of using a staging base near the final destination to change air crews and to refuel transports. This goal is also in conflict with the current practice of routing returning transports through an AMC base for maintenance and crew change. Thus, minimizing the number of stops can complicate achievement of other objectives, such as easing crew changes, efficiently using air crews, and minimizing ground time at APODs. These trade-offs seem to warrant additional consideration because of their effect on airlift delivery capabilities.

Initiative 9. To help aerial refueling increase daily deliveries, the Air Mobility Command should more fully explore the costs and benefits of alternative policies governing routing of those transports that can receive aerial refueling.

Can Aircrews Be Repositioned to Help Aerial Refueling Increase Deliveries?

Should the aircrews be repositioned to minimize the number of times that aircraft must land, or should aircraft make additional stops at the locations of aircrews for their convenience? A lesson from our research is that daily deliveries are maximized by minimizing the number of times that transports must land for either fuel or crew changes. This drove our analysis to routing concepts that are different from the Air Force's current procedures.

Initiative 10. To explore whether daily delivery capacity might beneficially be increased by changing aircrew positioning policies, especially when aerial refueling is available, the Air Mobility Command should more fully analyze the costs and benefits of alternative concepts for positioning aircrews.

Can Payloads Be Increased to Help Aerial Refueling Increase Deliveries?

Although average payloads for military-style transports are about as high as they can be, given the distances normally flown and given the range performance of the aircraft, can payloads be increased by more fully using the volume of the cargo cabins when aerial refueling is available? If cargo could be packaged to exploit the volume of cargo cabins more fully, payloads could be increased. For example, the private sector has learned to make full use of the available volume by developing special containers that are contoured to fit the shape of the cargo cabin. If average payloads could be increased by 50 percent—without unacceptably lengthening loading and unloading times—and if many en route stops for refueling and crew changes could be eliminated, aerial refueling would have the potential of doubling daily deliveries.

Initiative 11. To try to increase payloads, especially when aerial refueling is available, the DoD should consider initiating exploratory demonstration programs that would develop and test concepts for more densely loading transport aircraft.

How Should the Costs of Aerial Refueling Be Allocated?

Should the costs of aerial refueling be included in analyses of alternative airlift fleets, and if so, how? In our analysis we calculated the number of tankers that would be needed for contingency operations by the one fleet mix in which tankers were used (Option D in Chapter Four of Volume 2) to increase daily deliveries in lieu of procuring and operating additional transports. We assumed that those tankers would be assigned to designated transports and would train with those transports during routine operations. We believed it reasonable, therefore, to allocate all of the operating and support costs attributable to the routine operation of those tankers to the cost of the one fleet mix in which aerial refueling was used.

However, given the large number of tankers in the inventory and given the different ways they can be used, one could argue that there should be no costs (or only partial costs) assigned to the airlift fleet option. This is a potentially significant issue in the future, because the fleet options that include C-17s have a greater likelihood of needing tanker support, especially for westbound deployments against headwinds. (In our analysis of an eastbound deployment, however, we assumed that there was no need for tanker support of the C-17 fleet.)

Initiative 12. To ensure the inclusion of all significant costs that are relevant to selecting the right fleet mix, the DoD should consider adopting policy guidelines regarding how tanker costs should be included for those fleets that require tanker support in particular scenarios.

FLEET OPERATIONAL ISSUES (TOPIC 80)

Are Command, Control, Communication, and Computer Processes Improving Sufficiently?

Are current plans and programs to upgrade C⁴ capabilities sufficient to provide (1) reasonable exploitation of opportunities to increase daily deliveries from current airlift resources and (2) the capabilities necessary to absorb effectively a greater dependence upon civil-style transports?

Initiative 13. To acquire quickly those C⁴ improvements most essential to improving daily delivery capacity and to open the possibility of greater reliance on civil-style transports, the DoD should consider calling upon a broad cross section of experts to review and monitor plans, progress, and opportunities to accelerate and/or refine the focus of needed C⁴ developments.

Can AMC and Airlift Users Jointly Improve Loading Efficiency?

Especially in view of the possibility of a greater reliance on civil-style transports, should AMC and airlift users increase their efforts to improve the efficiency of loading transports? Transports must flow smoothly through APOEs to maintain high levels of loading efficiency. The transport must not be delayed waiting for a loading posi-

tion to open at APOEs; loads must be ready and efficiently packaged to use each transport's available volume; and the loading process must proceed in an orderly fashion.

Initiative 14. To explore the costs and benefits of increasing daily delivery capability by more efficiently loading transports, the DoD should consider convening a broad cross section of experts to review and refine planning guidelines, coordination procedures, resources, training, and loading processes to ensure (1) that a sufficient number of APOEs are used to avoid congestion-induced delays, (2) that adequate notice is provided to APOEs about the types of transports en route so that loads can be arranged to use each transport's available volume, and (3) that adequate APOE facilities (including runways of adequate length to allow maximum performance by the transports) and personnel are provided to make the best use of each transport.

Could APOEs Be Consolidated to Increase Daily Deliveries?

Because the servicing of too many APOEs can contribute to inefficient use of airlift resources, can the number of APOEs be consolidated to facilitate more-efficient assignment of aircraft, more-efficient use of ground resources, and more-efficient loading of aircraft? During the Gulf War airlift, transports were dispatched to over 100 airfields in the United States to pick up loads destined for the Gulf War theater. It is difficult for the airlift system to achieve the higher levels of efficiency that are needed to increase daily deliveries when so many locations must be serviced.

Initiative 15. To explore the possibility of increasing daily deliveries by reducing the number of APOEs, the DoD should consider initiating research that would develop and evaluate alternative concepts for reducing the number of APOEs, including the possibility of spoke-and-hub arrangements.

ILLUSTRATION OF THE POTENTIAL FOR SYNERGISTIC EFFECTS

Combinations of initiatives can sometimes create interesting synergistic effects. For example, consolidation of APOEs might facilitate other initiatives and in combination yield beneficial synergistic effects. Consolidation could do the following:

- It could make crew changes at APOEs a more viable policy option for the consolidated APOEs, in turn increasing the opportunity for aerial refueling to increase daily deliveries.
- It could allow a concentration of loading specialists and special containers that might help increase the use of the available volume in transports, thereby also increasing the opportunity for aerial refueling to boost daily deliveries. Such a boost may make aerial refueling a more attractive proposition from a cost vantage point than was the case with Option D.
- It could reduce the burden on development of the C⁴ capabilities needed to match aircraft and loads.
- It could ease the integration of additional civil-style transports into airlift operations.

Of course, there would also be costs in the form of transportation expenses to move units and materiel to consolidated APOEs, and there would be delays initially in delivering the first units. On the other hand, if daily deliveries were increased significantly for the consolidated APOEs, it might be worth the costs. This is just one of many possibilities awaiting further research as the DoD continues its efforts to define the best airlift fleet for the future.

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